LEVEL III

AD A092605

Engineering for Deep Sea Drilling for Scientific Purposes

Final Report

DTIC ELECTE DEC 4 1980 S C

Contract NSF C310, T. O. #388

The National Research Council

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Marine Board

Assembly of Engineering

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ENGINEERING FOR DEEP SEA DRILLING FOR SCIENTIFIC PURPOSES,

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Final Report,

11 1980

Prepared by the

Committee on Engineering Considerations for Continuation of Deep Sea Drilling for Scientific Purposes

of the

Marine Board
Assembly of Engineering
National Research Council

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NATIONAL ACADEMY OF SCIENCES
Washington, D.C., 1980

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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report represents work supported by Contract Number NSF C310, Task Order #388 between the National Academy of Sciences and the National Science Foundation.

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PREFACE

This report contains the findings, conclusions, and recommendations of the committee that has completed an engineering review of the proposed plan by the National Science Foundation (NSF) to drill deep into the ocean floor for scientific objectives. The plan as presently drawn calls for a decade-long, $700 million project that has been described as "the scientific exploration of one of the earth's last unexplored frontiers."

In considering whether to expand the scope and duration of its present deep sea drilling program, originated in 1968, NSF asked the National Research Council to review the technical soundness of performing the scientific work. In particular, NSF asked for an evaluation of the capability to conduct the proposed program in an environmentally safe manner within acceptable limitations of time and cost.

In response to the request, the National Research Council appointed a special committee under the auspices of the Assembly of Engineering's Marine Board in June 1978. The committee consisted of experts in ocean geology, seismology, marine engineering, offshore resource recovery, ship design and navigation, and political, environmental, and management matters.

Specifically, the committee was charged by NSF to:

- Relate the technology for drilling and obtaining core samples in the deep ocean to the objectives of the proposed scientific program, with particular emphasis on the technical feasibility, capability, and prospects for overcoming the anticipated problems presented by extreme depths, seabed properties, and forces of wind and current.

- Consider alternatives to drilling that hold promise of achieving the program's objectives.

- Examine in particular the riser and well control systems, as well as related technology, including the probable environmental effects caused by system failure, and the costs of such systems.

- Assess the options and costs of alternative drilling platforms.

- Compare the costs of various methods by which the program's objectives could be met.

- Assess the relationships between the federal government and the drilling industry, as well as the relationships among government agencies with interests and concerns in deep sea drilling.

In conducting its study, the committee met six times--twice each in Washington, D.C., and Boulder, Colorado, and once each in LaJolla, California, and Houston, Texas. In August 1978, some members visited the Glomar Explorer, which has been proposed as a drilling platform for the project, at San Pedro, California. In addition, ad hoc task groups met several times in the summer and fall of 1979 in Houston to review specific technical problems in connection with riser and well control.

From the beginning, the committee limited its study to strictly engineering considerations. It did not attempt either to relate the continuation of deep sea drilling to other research programs sponsored by NSF or to evaluate and rank the scientific objectives the program is intended to achieve. In its study, the committee dealt with technical issues such as project and engineering management, drilling platforms, drilling systems and well control, operational safety, environmental impacts, and personnel training.

Even so, this report does not represent a complete evaluation of the technology for drilling in the deep sea. It provides a snapshot in time of a rapidly evolving program. NSF is now in the process of defining the objectives of its program in light of the changing needs of the scientists involved and the means of supporting and accomplishing those needs. Thus, this report is concerned with only one early phase of evaluation in what will eventually be an on-going assessment of engineering requirements and program management by NSF and its advisors. The information base for the assessment in this report is the scientific and programmatic guidance provided by NSF and its science program advisor, the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES), as of September 1979.

Given the absence of final program definition by NSF at that time, this report does not endorse any one drilling system. While one may appear better suited to the goals of the program now, another may become more appropriate as the objectives become better defined.

To meet the current objectives, which include drilling under 13,000 feet (4 kilometers) of water and penetrating as much as 20,000 feet (6 kilometers) of the ocean floor, NSF has emphasized the capability of the Glomar Explorer. While the committee fully recognizes the unique capabilities of this ship as a drilling platform, it urges NSF to continue to assess alternatives as the program is further defined.

To meet the needs of NSF and the Congress for timely information to help plan the deep sea drilling program, the committee issued an interim report in November 1978. That report related drilling technology to the program's objectives, considered alternative platforms and their costs, compared the cost of various means by which to achieve the program's objectives, and assessed technical relationships between NSF and the drilling industry.

In this, its final report, the committee summarizes the conclusions and recommendations made in its earlier interim report, and characterizes NSF's response to them. This report also addresses problems associated with managing the project and its engineering systems, documents the evolution of the technical requirements for a platform and drilling system, and relates the science objectives of NSF to the engineering systems and technical problems. Finally, the report notes the engineering uncertainties posed by the program requirements.

A number of terms common to offshore drilling operations and structures, as well as ship stability, are defined within the text; however, some definitions are sufficiently extensive to be included in the Glossary. Whenever this arises, the words are indicated by an asterisk.

In issuing its final report, the committee acknowledges with gratitude the contributions made by others to its deliberations. Those individuals who assisted the committee's study are listed in Appendix A.

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SUMMARY

Since its inception in 1968, the Deep Sea Drilling Program sponsored by the National Science Foundation (NSF) has expanded our knowledge in the earth sciences by verifying the plate tectonic theory of the earth's crustal dynamics. Now, NSF is considering whether to extend the program's scope and duration. Under a plan proposed by NSF, the program would seek to recover sample cores from geological formations located as much as 20,000 feet (6 kilometers) below the ocean floor in water up to 13,000 feet (4 kilometers) deep. This difficult venture, known as the Ocean Margin Drilling Program, emphasizes penetrating the continental margins in deep sediments where oil and gas under great pressure may be encountered.

Such depths have never been so explored. The demands imposed by the ocean depths, drilling penetration, and personnel and environmental safeguards exceed today's operational experience as well as the capability of available systems and equipment. Using current technology, the seabed can be drilled to as much as 6,000 feet (1.8 kilometers). Still, no insurmountable technical barriers are foreseen that should prevent NSF from achieving its drilling objectives. In doing this, the cost of developing the equipment to meet the requirements of the proposed drilling is likely to amount to $84 million.†

Clearly, a concerted design and development effort will be required to build and test the drilling system. Such an effort should be based on a systems engineering approach--one that includes the drilling platform itself. The Glomar Explorer is considered the best available platform to drill in the deep sea. But the conversion from its original heavy-lift capability to a drillship platform should await the conclusion of comprehensive engineering studies. These will produce the specifications, plans, and schedules for an integrated, reliable, and safe system. Such studies could require at least two years to complete. Their results are necessary before the ship conversion proceeds or the hardware is purchased.

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†Reference Table 1, page 18. This estimate takes account of an annual 7 percent increase for monetary inflation. Based on 10 percent annual escalation, the cost is estimated at $100 million.

NSF should take advantage of this interval to plan its deep sea drilling program, with the assistance of its contractors and advisory committee. In laying its plans, NSF needs to:

- Develop early a strong administrative capability within NSF to handle technical planning and communication with industry and international organizations, as well as contract for technical administrative support where appropriate.

- Set out technical specifications for the drilling system, including the integration of the various elements of the system.

- Recruit and train the needed personnel.

- Specify the equipment and procedures required to ensure the safety of personnel and protection of the environment, including the use of backup systems.

- Provide a drilling and coring program, consistent with the scientific goals, that is cost-effective and technically feasible.

As the committee has observed in its interim report, it is unlikely that the offshore oil industry will reach the stage of its own hardware development in time to meet the needs of the NSF program's proposed drilling objectives and schedules. Therefore, new drilling systems have to be designed for deep penetration and minimum core diameter, as well as to withstand great horizontal forces imposed by ocean currents and waves.

The wellhead must be capable of supporting riser* loads greater than those encountered to date in offshore drilling. The need to protect the environment during the initial drill penetration is coupled with the design and specification of surface casing* to support the wellhead* at the seafloor. In addition, to protect the system against the sudden release of shallow gas, a packer or downhole blowout preventer* may be needed.

The deployment and use of a riser during the setting or installation of surface casing raises a fundamental problem: the casing is likely to be too large to go through the riser. Employing an offset riser while installing surface casing of a larger diameter may be the solution to this problem. The design of a riser system with fixed or controlled buoyancy requires a design study that needs to be ultimately linked to obtaining reliable environmental data from the drilling area and site. Finally, the development of the well control system, which includes blowout preventers, well casing, and downhole instrumentation, must be based on an integrated, system engineering effort that increases the reliability of well control response.

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*Refer to the Glossary.

All of these components are essential because the sudden release of high pressure gas (or "kick") into the drilling column presents serious hazards to personnel safety, environmental stability, and equipment integrity. At the depths proposed in the NSF program, new devices may be needed to control the rate of gas flow at the wellhead, rather than the conventional choke or kill-line methods by which control is exerted at the surface. Seafloor chokes, which may be desirable or even necessary, are under development but have not yet been tested.

In addition, a manned submersible or a remotely controlled vehicle may be needed to enable the operators to see and perhaps manipulate the wellheads at depths of up to 13,000 feet (4 kilometers) of water. Such vehicles are not now commercially available. To develop them will require high investment costs and long lead time.

Information and understanding about winds, waves, and currents is required at each site over a long time. Geophysical surveys, both of the reconnaissance and close-grid types, should be undertaken to determine where such information can be obtained with minimum risk. Next, the sites should be evaluated for their soil-mechanics properties to determine the adequacy of support for the foundation structure. Currents should be measured over a year or more along the entire water column. This will permit NSF to better design the drilling system, in which well control is a key concern.

Normal deep sea drilling operations for scientific purposes appear to have a slight, localized, and transitory effect on marine organisms and a longer lasting, although still local, influence on the bottom community. Loss of a riser in the deep sea would pose no threat to the ocean ecosystem as a whole, but it would be a continuing threat to local organisms. The major concern is possible environmental damage from a petroleum blowout. While there is no experience with a blowout in the deep sea, if one did occur the oil would spread in deep water. Because bacteria are less active there than in shallow water, oil could remain in the deep sea for years.

The small likelihood of a blowout is reduced even further if the site is first properly surveyed and if drilling is closely monitored. Even so, the precautions that must be taken to prevent a blowout will affect drilling procedures, contingency planning, personnel training, equipment qualification and operating instructions, and key hardware redundancy, as well as equipment design.

Because of the time and cost needed to acquire high-quality core samples from the ocean bottom, NSF should aim for cores of uniformly good quality and continuity. Toward this end, NSF should encourage the development of better cones, bit loading and torque controls, and downhole instrumentation during and following drilling. Retrieving cores of scientific quality is particularly difficult when drilling into the ocean crust. Accordingly, the equipment should be tested in the field before it is used in the program.

Of the alternatives for use as a drilling platform--submarines, semi-submersibles, and floating ship-shaped platforms--a large ship is considered to be best. In addition to on-board storage for drilling pipe, riser sections, and casings, a ship has adequate space for laboratories where cores can be analyzed. With such a ship, frequent trips to transfer men and equipment from the drilling site to land-based facilities will be avoided. Moreover, a ship can move from site to site faster than a semi-submersible.

Among all possible surface platforms capable of meeting the proposed goals of the NSF program, the Glomar Explorer provides the best available platform to drill in the deep margins where complete well control is required. For other scientific objectives, however, various surface platforms could be used, including a leased ship that could be a "test bed" for intermediate depth drilling systems that use a well control system. The operation of the Glomar Challenger could be extended beyond 1980 to permit riserless drilling until Explorer, or a similar large platform, becomes available. The committee recommends that this alternative be given further consideration by NSF.

While the transfer of technological know-how from the United States to other countries can be a sensitive issue, the national security and economic interests of this country are not threatened by the normal demands for scientific or technical information about deep sea drilling. However, a subject of greater concern affecting participation and cooperation is the implication of expanding the deep sea drilling program to explore for and determine the potential for finding natural resources. NSF does not now plan to use its scientific program to explore for or to recover oil and gas or other resources from beneath the ocean floor. Hence, the avoidance of on-structure drilling should be a NSF policy to preserve international cooperation, as well as to encourage industrial support.

The committee views the support and participation of industry in the engineering development phase of the program to be essential to timely, safe, and cost-effective performance. The extent and methods by which this participation can be achieved have not been addressed by the committee because such matters are outside the scope of this study.

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INTRODUCTION

Since its inception in 1968, the Deep Sea Drilling Program (DSDP) of the National Science Foundation (NSF) has helped confirm the plate tectonics theory of seafloor spreading and more recent ideas about ocean basin circulation. In this effort, the Glomar Challenger has served as the drilling platform, under the direction of Scripps Institution of Oceanography. NSF's Ocean Sediment Coring Program has supported much of this work, with scientific advice provided by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES)†.

The results of the last decade suggest that by continuing deep sea drilling during the 1980's knowledge of oceanic margins and the earth's crust may be gained to advance understanding of the processes of earthquakes and volcanoes, as well as identify potential deposits of minerals and fossil fuels. Called the Ocean Margin Drilling Program (OMD), the NSF program would continue deep sea drilling at sites where the outer continental shelf slopes to the deep ocean basin (the continental margin), as well as in crustal areas of the ocean abysses.

Although scientific and other objectives of the proposed program are still evolving, new engineering and support capabilities beyond the simple extension of present offshore industrial practices will be required. The program will need new platforms and systems for safe drilling on the continental margins in deep sediments where high pressures may be encountered.

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†U.S. members of JOIDES are: the Lamont-Doherty Geological Observatory, Columbia University; University of Washington; the Woods Hole Oceanographic Institution; Scripps Institution of Oceanography, University of California; the Institute of Geophysics, University of Hawaii; the University of Rhode Island; Oregon State University; and Texas A&M University. Also, within JOIDES, scientific members include institutions in five foreign countries: Japan, the United Kingdom, France, West Germany, and the USSR.

The scientific program, as originally proposed by JOIDES† and subsequently modified, calls for studies of the ocean crust and paleoenvironment. It also proposes a detailed investigation of the ocean margins. As an unprecedented new initiative, this effort calls for recovering core samples of the earth from penetrations as deep as 20,000 feet (6 kilometers) below the seafloor under 13,000 feet (4 kilometers) of water.

The equipment for achieving these penetrations and depths was characterized as a "13,000 feet drilling system" by the committee and served as a basis for its engineering considerations. The characterization does not constitute an endorsement of any specific scientific objective or of its relative priority to the nation. Even though various elements of the scientific program were changed as the study progressed, the committee based its examination of engineering considerations on the most technically demanding set of scientific objectives in terms of water depth (13,000 feet) and safety requirements to protect the personnel and the environment. The capability required to meet the demands of such advanced drilling far exceeds present practice.

The technology for drilling at such depths requires advanced well control capability, including a marine riser, to provide for environmentally safe drilling in regions where hydrocarbon deposits and abnormal pressures may be encountered unexpectedly. In addition, the well control system includes a blowout preventer, installed at the wellhead, as well as instruments and controls.

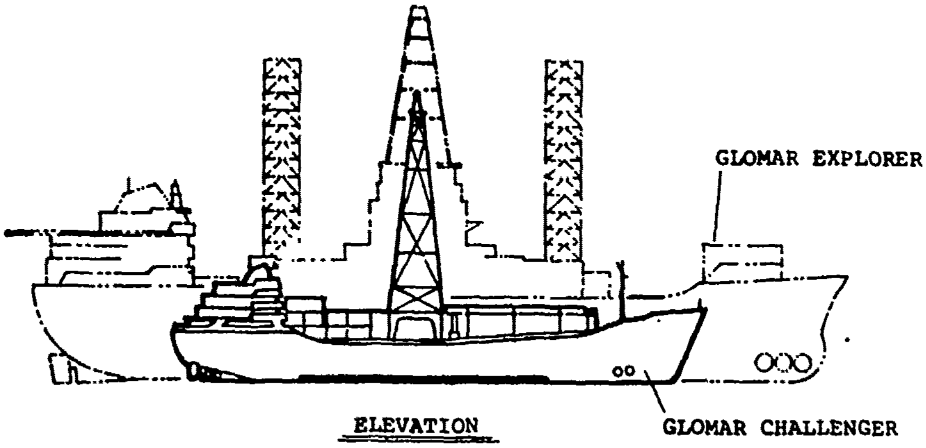
Moreover, advanced drilling technology is required to attain the objectives. The program has to be preceded by extensive engineering and scientific preparation. In addition to analysis and evaluation, the program will extend the use of present-day equipment to new environments. When drilling begins, time on station will be five to ten times longer than typical for recent deep sea drilling operations with _Challenger_. This will present arduous operational, training, and logistical challenges.

The advanced drilling system examined most closely by the committee calls for conversion of the government-owned, heavy lift vessel, _Glomar Explorer_ as the platform component of the drilling system. Other platform alternatives were examined in less detail and only in relation to the most technically demanding set of objectives, which are part of the passive margins drilling program. Changing these objectives as they relate to water depth would affect the evaluation of alternatives, including the conclusions that led the committee to focus on the _Explorer_.

(Major parameters of _Explorer_ and _Challenger_ are shown in Figure 1.)

†The report, "The Future of Scientific Ocean Drilling," (FUSOD), July 1977, established the initial benchmark science plan for NSF. It is discussed later in this report.

	EXPLORER	CHALLENGER
DISPLACEMENT	21000 LT LIGHTSHIP	4303 LT LIGHTSHIP
LENGTH	618 FT	400 FT
BEAM	116 FT	65 FT
DEPTH	51 FT	27 FT
HULL VOLUME	3000000 CU/FT	600000 CU/FT



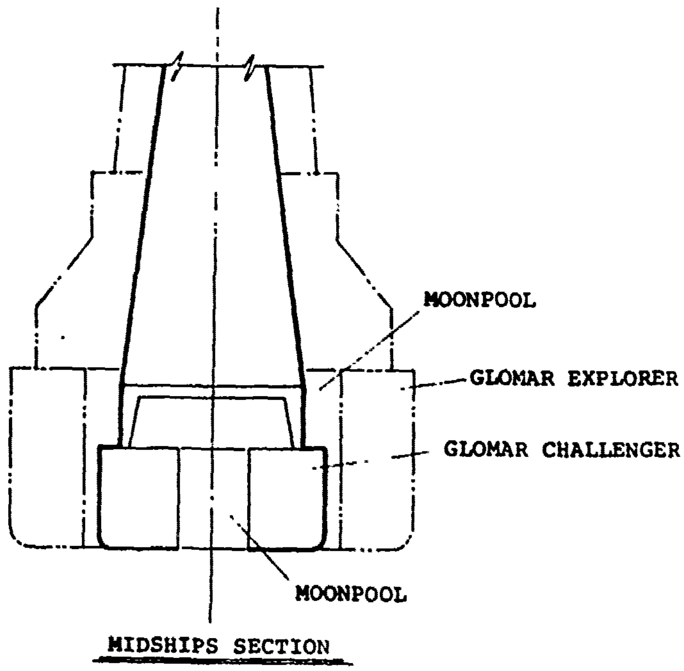


Figure 1 Source: Global Marine Development, Incorporated, "Feasibility Study for Conversion of Glomar Explorer into a Deep Water Drilling and Coring Vessel," Final Report, Vol. 1, Page 2. U.S. Government Contract UC-NSF-C482.

INTERIM REPORT AND RESPONSES

Prior to issuing its interim report in November 1978,[1]† the committee devoted its attention to a discussion and review of the engineering information and implications of the scientific program proposed in the JOIDES report, "The Future of Scientific Ocean Drilling."[2] This report and related documents advanced a broad spectrum of scientific objectives that might impose widely different requirements for ocean drilling technology.

As an example of the diversity of objectives and their implications for the development of the NSF program, the *Glomar Challenger* or a similar drillship might undertake the projected Ocean History/Paleoceanography Program with improved work capability in bad weather and in moderate ice conditions. Similarly, *Challenger* could undertake portions of the Ocean Crust Program as well as much of the Arctic Margins Program with improved coring techniques and hard-rock drilling capability. On the other hand, the Passive Margins Program depends on deep penetration of sedimentary layers that cover the underlying structure of the margin. In this situation, riser capability is essential to safeguard the environment. It is also needed to circulate cutting fluids in order to attain deep penetration during drilling operations in passive margin sediments where hydrocarbon deposits might exist. Developing such a drilling and well control system is the major technical challenge to the proposed extension of deep sea drilling for scientific purposes.

Thus, the committee considered it to be central to the program that NSF evaluate the required combination of platforms, drilling, and coring systems to determine the optimum set of facilities and drilling schedule. NSF should also examine the feasibility of the development schedule and determine those costs that depend in particular on more specific drilling information and drilling site plans. When the interim report was prepared, such information was not available to the committee. Therefore, the committee recommended that NSF develop specific drilling and coring information (e.g., drilling depth and penetration, core size, general site location, and intended operating procedures) as well as detailed schedules. This information was needed to systematically evaluate technical, management, and schedule issues.

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†See list of References, page 63.

Fully aware that NSF had not defined sufficiently its operational objectives for the deep sea drilling program, (i.e., drilling sites, depths, earth penetration, and schedules), the committee was unable to fully assess the engineering requirements and costs associated with the expanded operations. Instead, the committee deliberated on the information that was available and reached several conclusions and recommendations.

Conclusions of the Interim Report

With regard to acquiring subsurface geophysical data, the committee did not identify any practical alternatives to conventional rotary drilling. Scientific data is ultimately dependent on acquisition of core samples.

In its preliminary assessment, the committee did not identify any insurmountable technological, safety, or environmental barriers to a continuation of deep sea drilling for scientific purposes. However, a more comprehensive assessment and a major engineering effort will be required to verify this conclusion. In particular, several areas were identified that warrant special attention prior to firm program definition and procurement of equipment to reach the goal of penetrating 20,000 feet (6 kilometers) into the ocean floor under 12,000 feet (3.7 kilometers)† of water. In some areas, such as ship positioning and selected riser components, today's engineering can be safely and successfully extended to attain these goals. It is clear, however, that special efforts will be required to engineer and design an integrated ocean drilling system. It appeared unlikely that industry, with its different priorities and timetables for deep ocean drilling, will undertake on its own the necessary development and design of such a system in the foreseeable future.

Of the three drilling platforms considered--surface ship, submarine, and semi-submersible--the committee viewed the surface ship as being the most technically feasible to support the deep ocean drilling program in the next three to four years. At the time the interim report was prepared, the Glomar Explorer was being seriously considered by NSF as the drilling platform to support the scientific program described in the FUSOD report.

Interim Report Recommendations and NSF Responses

In its interim report, the committee recommended that NSF help advance the development and evaluation of technical alternatives and provide a better basis to estimate costs for an environmentally safe continuation of its deep ocean drilling program for scientific purposes. NSF responded to the committee's recommendations in a positive, favorable, and rapid manner. NSF extended the contract of Donhaiser Marine, Incorporated (DMI), through October 1979 to

†This objective was later changed to 13,000 feet (4 kilometers) during the evolution of NSF planning.

continue review of certain recommendations and to provide other technical assistance until the engineering support contractor could be selected and task assignments made.

The following list compares the committee's recommendations with specific NSF action:

- Recommendation: Undertake the conceptual design of an integrated drilling system that can accommodate the required loadings. Specific concerns focused on such areas as platform station-keeping, riser design and deployment, and well control systems.

  - Response: NSF has acknowledged the importance of the system engineering approach and asked DMI to continue its studies in these key system areas. Conceptual riser designs were investigated by DMI and preliminary estimates of operating limits of the system have been proposed.

- Recommendation: Establish a current profile for design use in calculating the force of the ocean currents (hydrodynamic loadings). Data used for this purpose should be based, if possible, on direct measurements.

  - Response: DMI has searched published and unpublished sources for oceanographic data. Some data have been obtained and are being used to establish a current profile for preliminary riser studies. This issue, however, continues to be of concern and is discussed later in this report.

- Recommendation: Identify equipment requirements and procedures for normal and emergency disconnection of the riser.

  - Response: DMI has identified some of the problems requiring further study. Definition of these requirements is included in the tasks recently assigned to NSF's engineering support contractor.

- Recommendation: Design a wellhead/foundation assembly that can support riser imposed loads.

  - Response: DMI has estimated riser operating limits that will be useful in estimating loads for preliminary wellhead/foundation design. The tasks of the NSF engineering support contractor now include developing riser operating limits that will be useful

in estimating loads for preliminary wellhead/ foundation design. They also include studying the requirements for the drilling system and developing work specifications that will be done later by a system integration contractor.

- Recommendation: Evaluate the ship power and station-keeping capability of the Glomar Explorer by tests at sea. Provide a failure mode analysis of the ship's power/propulsion system.

    - Response: The Glomar Explorer was tested at sea in February 1979 with the cooperation of Lockheed and Global Marine Development. DMI supervised these tests and analyzed the data. DMI's final report discusses vessel response and station-keeping. Specifically, DMI recommended changing propellers on the main shaft and adding two thrusters.† NSF intends to continue these studies, through their engineering support contract, to develop final performance specifications.

In its interim report, the committee urged that immediate attention be given to establishing a project management and systems integration team that would provide NSF with the necessary engineering support in the formulation and analysis stages of the proposed program. In response, NSF selected Santa Fe Engineering Services Company as the engineering support contractor.

†The DMI final report also recommends modification of the power distribution system. The NSF engineering support contractor will perform failure mode analysis of the system.

SCIENTIFIC OBJECTIVES

Science Planning

In its 1977 FUSOD report, JOIDES called for a program throughout the 1980's of deep drilling in passive and active margins, shallow coring in the ocean crust, and paleoenvironmental studies in the ocean sediments.[3] According to FUSOD, drilling in the margins will require marine-riser drilling systems to protect the environment and ensure the safety of personnel. These drilling systems, which must be employed in areas where potential hydrocarbon-bearing or geopressured formations exist, include well pressure control components in addition to a riser. In crustal drilling, coring productivity and quality may be enhanced by the improved drilling characteristics provided by the cutting fluids of a riser system. The FUSOD report also discussed several drilling platform options including Explorer.

A later science planning report[4] by an ad hoc advisory group established by NSF and chaired by B. J. Gilletti, generally supported the conclusions of the FUSOD study. However, it also urged an extension of drilling depth to 18,000 feet (5.5 kilometers) and recommended improving platform ice resistance to permit operations in high latitudes in favorable weather.

JOI, Incorporated, in its science advisory role, has also increased its planning activity in coordination with industry, including the major oil producers, drilling companies, and several offshore engineering organizations. This planning has been encouraged by the President's Office of Science and Technology Policy. As a result, the schedule and costs of NSF's science program have changed from the earlier FUSOD report. They are still fluid, as science, engineering, industry, academia, and government participate in the decision process and a workable consensus of goals and objectives emerges.

The general science goals were first enunciated in the FUSOD report and form the basis for the description of NSF's plan for continuation of the deep sea drilling program:

- Passive Plate Margins: Investigate the evolution of passive margins, how continents break up, and how ocean basins are formed. Specific problems to be investigated are pre-rift (pre-break) events, rifting, drifting, and post-rift evolution. The most important areas are the ocean-continental boundaries.

- Active Plate Margins: Investigate the rapid geodynamic processes leading to deep-ocean trenches, high mountains, concentrated zones of earthquakes, and chains of volcanoes. A most important objective is to clarify tectonic processes† (i.e., subduction).

- Paleoenvironment: Study the evolution of the oceans from the single supercontinent and superocean that existed 200 million years ago to the fragmented system of oceans and continents that is apparent today.

- Ocean Crust: Reach a better understanding of the process of seafloor spreading. Specific areas of study include hydro-thermal circulation through the ocean bottom, spreading rates, heat transport from the mantle, aging of the crust, and chemical processes involved in alteration of deep-ocean crust.

Preliminary operational plans, including a program schedule to support the above goals, were provided by members of the scientific community at the request of NSF at the committee's meeting on September 10, 1979. These plans continue to evolve. However, certain consistencies are evident and form the basis for the assumptions that influenced the committee's technical considerations. The elements of the science plan of major concern to this report are:

- The continuation of the deep sea drilling program is scheduled only through 1988.

- Sediment penetration would not exceed a drillstring capability of 33,000 feet (10 kilometers). For example, drilling would not exceed 7,000 feet (2.1 kilometers) penetration in 26,000 feet (7.9 kilometers) of water depth. (Note: there is no implication of drilling with a riser at this depth and penetration.)

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†Tectonic: changes, and the forces causing change, to the earth's crustal structure.

- Since Explorer is too large to go through the Panama Canal, it will have to go around Cape Horn. Strengthening its resistance to ice would permit drilling operations in the southern seas (Scotia-Weddell Sea Area) while sailing to the U.S. East Coast.

- The first year and a half of the program would be engaged in riserless drilling operations in trench areas with drilling depths up to 25,000 feet (7.4 kilometers). Explorer would be the support platform. Following conversion, sea trials, and acceptance tests of Explorer, a final riserless drilling operation would be concluded in the southern seas at 12,000 feet (3.7 kilometers) depth.

  Following the addition and testing of risers, operations in the Atlantic will begin in 1985. They will include a series of long-term projects of 12 to 18 months each in passive margin areas, like the Delaware-New Jersey offshore region, at up to 13,000 feet (4 kilometers) depth and 20,000 feet (6 kilometers) penetration.

These objectives were reviewed by and are in accord with JOI, Incorporated, and NSF plans presented to the committee.

Background Studies

The value of the Glomar Challenger as a drilling platform for deep sea drilling was clearly evident by 1975. New opportunities for advances in earth sciences that would build on previous deep sea drilling experience were already suggested that would go beyond Challenger's capability. At that time, NSF sponsored several technical studies, directly and through the Scripps Institution of Oceanography, in anticipation of a need for extended drilling in the continental margins.

The first report in a series of NSF sponsored studies, issued in September 1975 by Ocean Resources Engineering Incorporated (ORE), concluded that a larger drillship (570 feet or 174 meters long compared to Challenger's 400 feet or 122 meters) would be needed to drill in ocean margins.[5] The report said it would need adequate well control systems at water depths up to 12,000 feet (3.7 kilometers) and earth penetrations up to 18,000 feet (5.5 kilometers).

By 1977, the possible availability of the Glomar Explorer, a government-owned vessel, was apparent to scientists. NSF asked Global Marine Development, Inc. (GMDI), to review the Explorer's research capabilities as a drillship. GMDI reported that Explorer,

after conversion,† could indeed meet or exceed the criteria for extended drilling operations presented in the ORE report.[6]

NSF then asked DMI to review and evaluate the ORE and GMDI studies. In its November 1978 report, DMI concurred with the ORE study and, with certain exceptions, generally agreed with the GMDI report.[7] Regarding the platform, DMI stated that "the <u>Glomar Explorer</u>, with suitable modifications, appears to be a feasible and financially attractive ocean margin drilling vessel." The report goes on to recommend an analysis of the possibility that <u>Explorer</u> could fail to keep its station. Further, DMI recommended a buoyed riser based on its opinion that a broad technology base already supports the concept.

Intensive review of NSF's science objectives and program planning for continued deep sea drilling, including ocean margin drilling, continued during 1979. An NSF-appointed ad hoc advisory committee†† concluded in July 1979 that drilling in the ocean margins is very important to both science and resource exploration and, while the cost (on the order of $700 million over 10 years††† is high, it is justified by the combination of scientific and resource oriented goals.[8]

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†The <u>Glomar Explorer</u> was originally designed for heavy lift missions. Conversion involves a number of structural changes to accommodate drilling and riser handling, storage, station-keeping ability, and possible operations in areas where ice is common.

††The NSF Committee on Post IPOD Science (International Phase of Ocean Drilling) was established and met in the spring of 1979 "to evaluate, in the context of the national scientific effort, a proposed program of drilling and related activities in the deep oceans for scientific purposes in the 1980's, and to make recommendations concerning the advisability of the National Science Foundation sponsoring such a program."

†††Estimated on the basis of 10 percent annual escalation; original estimates were based on 7 percent annual escalation. See page 18.

MAJOR ENGINEERING CONCERNS

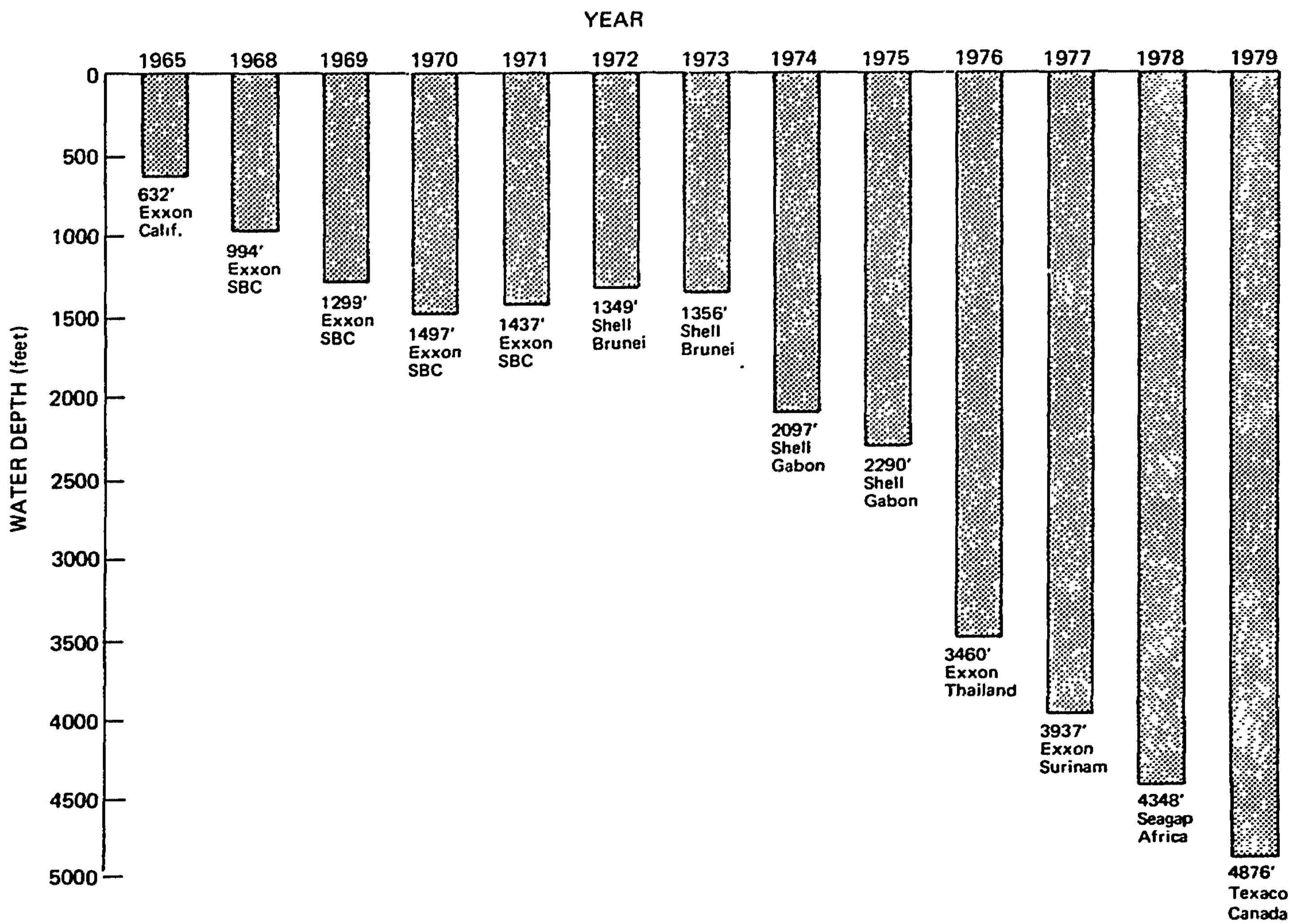
The proposed continuation of deep sea drilling covers a wide range of management, engineering, operations, hardware, and system needs. The committee has reviewed in detail those needs and the state of the art of the technology for satisfying them.

The technology is clearly sufficiently advanced to support the engineering requirements of continued deep sea drilling, but the state of practice must be extended in practically every instance. As an example, the general trends in industrial capabilities for deep sea drilling with risers are illustrated in Figures 2 and 3, which present the maximum water depths at which such drilling has occurred each year over the last 15 years.

The rates of increase in depth capability vary since they depend on the intensity of effort expended and on the incentives that exist for reaching greater depths. Even if the maximum rate of increase shown in Figure 3, from 1973 to 1976, should occur again between 1980 and 1984, industry may not be ready to support the desired 13,000-foot (4 kilometer) riser drilling capability at the time NSF's schedule indicates that it is needed. Consequently, it is indeed imperative that a concerted design, development, and test effort by NSF will be required to satisfy the needs for the riser and well control.

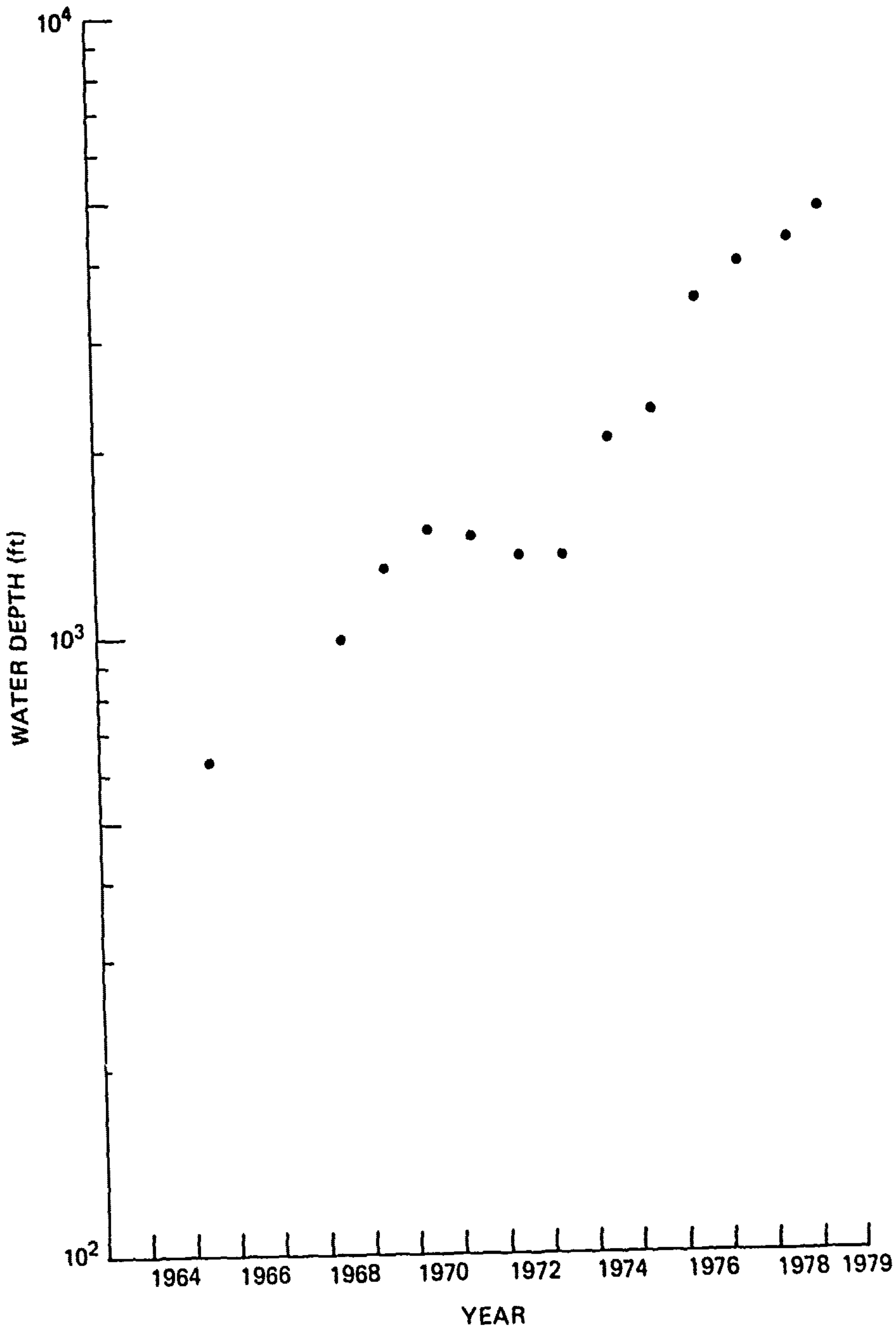
A similar situation exists for coring devices, which are vital since an adequate understanding of essentially every portion of the geological formations to be studied depends upon acquiring good cores. Deep sea scientific coring equipment is likely to differ, in materials and design, from that normally supplied by industry today. In addition, the schedule to develop special coring equipment is not likely to be met without support by NSF.

In view of the situation illustrated by the two examples just noted, the committee reviewed each major item of the drilling system to define the major uncertainities and to develop recommendations upon which NSF could base its program management and development efforts. The remainder of this report analyzes those reviews.



SOURCE: EXXON Production Research Co., based on information furnished by Offshore Rig Data Services, P.O. Box 19247, Houston, Texas, 77024.

Figure 2 Water Depth Records for Offshore Drilling Operations with Risers



SOURCE: Committee staff.

Figure 3 Water Depth Records, Deep Sea Drilling with Risers

Program Management

Planning and Management - A Major Issue

The committee's early deliberations were devoted to exploring technical issues that could impede or preclude achieving the water depth and penetration goals. Various areas were identified as requiring development beyond the current state of practice. These are discussed :lly in the section on major design issues. None, however, seemed insurmountable given the requisite engineering effort in their solution. Gradually, over the course of several meetings and numerous discussions with NSF project management personnel, the committee shifted its focus from specific technical issues to program planning and management. By the end of the committee's tenure, its primary concern was the potential pitfalls of inadequate planning and preliminary design engineering plus a shortage of competent program management staff.

From within and from invited guests, the committee drew on experience in advanced technology system procurement. A clear pattern emerged. Without a methodical and comprehensive procurement plan and an appropriate management and technical staff, the effort to procure an advanced technology system is unlikely to achieve its performance goals and will exceed its cost and schedule objectives.

Although the committee addressed this observation in its interim report, subsequent discussions with the NSF led it to a decision that this point needed amplification in the final report. The outcome of this decision is discussed in Appendix B, which spells out in depth the essential steps for minimizing risk associated with engineering development and procurement of the required deepwater drilling system. In addition, a special effort was made to review industry procurement in an analogous situation; this is discussed in detail later in this section. Without early and adequate attention to this activity, identification of critical technical issues will be of little value to the continuation of deep sea drilling for science, under any program requiring major development.

Other Management Issues

The international- and national-interest aspects of deep sea drilling will require careful attention as the program develops. Specific courses of action will depend strongly upon White House decisions that exceed NSF's authority.

In general, prior experience in deep sea drilling has laid a strong foundation for international scientific cooperation. However, more thought and safeguards may be needed to protect such national interests as patent rights and technology transfer to foreign nations. Adequate environmental protection will require

recognition of and adherence to the safety and environmental regulations of other nations in whose waters drilling may be planned. This subject is discussed further in the section on operational safety.

The overriding importance of central authority and expert staffing of the NSF management team should be reasserted and highlighted. In addition to the technological functioning groups, the team should have its own contracting authority, legal counsel, and personnel responsibility to ensure effective operations and to avoid costly delays in the pursuit of program objectives. These functions can be accomplished without undue staff increases within the program office by assigning specific individuals within existing offices the on-going responsibility to respond to the needs of the deep sea drilling program.

Although there are possible conflicts between the major engineering requirements of the program and its scientific goals, success depends on reconciling these conflicts. NSF must confront conflicts realistically from the start.

Budget and Schedule

Proposed Budget

In reviewing the budget requirements and program schedule, the committee used the NSF budget submission entitled "Future Scientific Ocean Drilling/Ocean Margin Drilling" as a benchmark--see Table 1. The numbers appear to be reasonable baseline estimates, with some modification. NSF used a 7 percent escalation figure that, while following government guidelines in effect at the time the budget was proposed, is clearly inadequate. The cost of drilling equipment has increased by 12 to 15 percent annually during the last three years. Overall drilling costs, including operating costs, are up by 25 percent. Thus, the total budget is low.

Additionally, the $37.3 million estimated for vessel conversion does not include probable changes in the power distribution and position-keeping systems. These costs could total $2 million. Completion of the contract design will likely result in further changes worth about $2 million.

NSF has not provided funds for gathering environmental data, which must be done in fiscal years 1980 and 1981. These costs, according to NSF estimates, may approach $5 million.

NSF should also consider hiring (or retaining) operating and drilling crews for the Glomar Explorer. They can be trained while the ship undergoes conversion and the drilling system is developed (see section on operational safety, environmental impact, and personnel training). This could require an additional $4 million to $6 million in funding.

TABLE 1

FUTURE SCIENTIFIC OCEAN DRILLING/OCEAN MARGIN DRILLING

Challenger/Explorer

1980 - 1989

Fiscal Years	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Total
I. Planning and Evaluation	3.6										3.6
II. Explorer Conversion and Riser Technology											
Vessel Conversion		16.7	20.2								37.3
Riser Development		13.4	10.1								23.5
Spare Riser System				23.6							23.6
Subtotal		30.1	30.7	23.6							84.4
III. Explorer Drilling Operations											
Explorer Operations 1/			9.6	24.8	26.5	28.4	30.4	32.5	34.8	2.0	189.0
Project Operations											
Management of ship operations 2/		3.0	7.0	8.9	9.1	9.7	10.4	11.3	12.0	1.0	72.4
Operations Engineering Support 3/		1.0	1.5	1.7	1.8	1.9	2.0	2.1	2.3	0.5	14.8
Science Operations 4/		2.0	5.7	5.6	5.5	6.0	6.4	6.9	7.4	0.5	46.0
Subtotal		6.0	23.8	41.0	42.9	46.0	49.2	52.8	56.6	4.0	322.2
IV. Science Programs 5/											
Geophysics		5.2	6.4	6.6	7.5	9.7	10.7	8.6	6.4	4.2	65.3
Sample Analysis		1.9	2.2	2.4	3.2	3.2	4.3	4.3	5.3	5.3	32.1
Site Surveys		4.6	6.1	6.3	6.1	6.3	6.6	6.9	7.3	0.5	50.7
Subtotal		11.7	14.7	15.3	16.8	19.2	21.6	19.8	19.0	10.0	148.1
Grand Total	3.6	47.8	69.2	79.9	59.7	65.2	70.8	72.6	75.5	14.0	558.3
Challenger Program	21.4	21.4	5.1								47.9
TOTAL, OSCP	25.0	69.2	74.3								606.2

NOTE: Above is new funding required (Dollars in millions); (1979 dollars -- escalation at 7 percent per annum)

1. Includes subcontract cost for direct operation of Glomar Explorer, including ship's and drilling crews, logistics support, drydocking and maintenance costs, and operating supplies, such as fuel, drilling mud, cement, etc.
2. Includes management personnel costs associated with overall operation of the Glomar Explorer and drilling systems. This figure includes reserves for placement of major system components such as drill string, riser components and other major expendable items.
3. Includes contract costs for the engineering support contractor to NSF for technical evaluation of proposals, changes, design of special systems and review of well programs.
4. Includes costs for science contractor responsible for operation of shore-based laboratories, core repositories, sample distribution, sci scientific data bank, scientific publications, shipboard laboratories operation and staffing. Also includes engineering to support downhole experiments and development of special scientific tools.
5. Science programs are related to the drilling program. Geophysics is problem definition in deep ocean and on ocean margins. Sample analysis is instrumentation and methods for shipboard and shore-based analysis of deep sea cores. Site surveys is delineation of specific drill sites for Explorer drilling.

SOURCE: National Science Foundation, September 10, 1979

Further, there will be increased dependence on high-resolution, geophysical seismic data, including reflection seismics, (discussed in the sections on operational safety and environmental impact); this could cost another $25 million to $35 million during the period 1982-88.†

In regard to the proposed multi-year budget, NSF's plans call for major commitments of funding for several years, an unusual procedure for agencies that operate on annual funding. Multi-year authorization in a manner similar to Maritime Administration or Navy ship construction is an established procedure that should be considered by NSF and Congress for this program.

Schedule for Development

A system support contract, which began in October 1979, is consistent with earlier committee recommendations that NSF strengthen its management team. NSF intends to undertake trade-off analysis and system definition to develop a clear set of requirements. It will also issue a request for proposal (RFP) to obtain a systems integration contractor in October 1980. NSF should provide more funds and allow more time to complete this work than it has so far. The magnitude of the engineering and design tasks outlined in the preceding section and discussed more fully later requires a minimum of two years to complete. This belief, expressed in the committee's interim report, has been strengthened by its continuing deliberations, and is further demonstrated by industry experience.

Industry Experience, Drilling System Development Program

To amplify its recommendations on planning and preliminary engineering, the committee sought a specific, high-technology industry case of procurement as an example. A worldwide operator of floating drilling units provided information on procurement of a deepwater drillship. This drillship serves as a good example because it was designed to double the then existing maximum water depth capability.

The following describes the steps in the procurement procedure and a few of the major technical issues. The operator was most candid with the committee in describing some of the problems that were encountered during the development and suggesting, in hindsight, how they might have been avoided.

The operator first established a future requirement to drill in up to 3,000 feet (915 meters) of water. At the time, the water depth record was less than 1,500 feet (458 meters). As a result of this requirement, the operator's production research division began an intensive review of technology with the final objective of preparing performance specifications for equipment suitable for

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†Basis of estimate: $1 million additional cost for each site drilled and 25 to 35 wells to be drilled over the period.

inclusion in a request for proposal submission to prospective contractors. Two years later, the research division provided vessel and equipment performance specifications. The RFP was reviewed by the operator's technical and management personnel and was then given to drilling contractors, who were given three months to develop their formal bid responses. After receipt of the bids, another three months were needed to evaluate the bids and select the prime contractor to build the deepwater drillship.

The drillship began operations about four years after the contractor was selected (and six years after preliminary studies were initiated). Even with this length of time for detailed design work and for industry advances to keep pace, a number of technical problems were encountered during construction and vessel startup operations. Examples specifically noted were:

- The riser buoyancy material selected originally was syntactic foam. Foam material capable of withstanding pressures at 3,000 feet water depth was not commercially available at the time the bid was awarded, but research and development work on the material was underway by industry. Technology did not keep pace with the construction schedule and the foam buoyancy failed pressure tests. As a result, alternate means for providing the necessary riser lift had to be developed and evaluated.

- The electrohydraulic control system design of the blowout preventer changed during construction to keep pace with both technology and the owners requirements, and consequently the cost greatly exceeded the original estimate. More detailed work to fully design the system prior to construction and use of proven components could have reduced the cost overrun. At delivery, the blowout preventer control system still had problems with solenoids used to control the various blowout preventer functions and with flooding of the hose/cable/connector assemblies where the cable was connected to the blowout preventer. After drilling only two wells, the decision was made to replace the new electrohydraulic blowout preventer control system with a more reliable all-hydraulic one of proven design.

- The dynamic positioning* or station-keeping system was initially plagued by poor performance of the thruster control system. Sea trials designed to verify acceptable performance of the system indicated that it did not respond properly during drilling operations. Four months were required to check out and upgrade the system to acceptable levels.

*Refer to Glossary.

- The special winches used onboard the vessel to maintain constant tension on the guidelines for the blowout preventer and other seafloor equipment did not work properly.

The operator's personnel were quite frank in stating their belief that many of the problems noted could have been prevented by alloting more time for: a) pre-engineering both the system and many of the components, prior to committing major items to detail design and fabrication, and b) component and integrated system testing and/or shakedown prior to beginning operations.

This experience reinforced the committee's view that an adequate RFP for the selection of the systems integration contractor can only be prepared after a much more detailed study than has presently been planned. Further, the contractor must complete still more detailed work before the final budget and fabrication schedule can be adequately defined and before work such as ship conversion can be started.

Although the industry analogy included two years of engineering preparation, it should also be noted that there were fewer uncertainties regarding the operational objectives compared with NSF's ocean margin drilling program. If there had been another level of review, similar to governmental program approval, more time would have been required.

General Concerns in the Program Planning

The schedule should allow time to define the system and to acquire environmental data on the geographic areas of scientific interest. Since neither the schedule nor the budget give sufficient provision to define the system and acquire data, the program should be rewritten (see sections on environmental influences and on operational safety).

The operating contractor should help develop the contract plans for converting the ship. Because of the relatively short time allowed the contractor to complete the plans and convert the ship, an operating contractor should be chosen as soon as possible (also see section on operational safety, environmental impact, and personnel training).

Because of the central role in carrying out the program, the systems integration contractor should have proven capability in major program administration, engineering development, and field operations. The NSF selection process must confirm the existence of these capabilities and obtain the firm commitment of the successful bidder to assign key personnel with the appropriate qualifications and experience. In this connection, a pre-bidding conference should be planned to ensure that all bidders understand the breadth of coverage needed. Because the drilling system will be operated over

a nine-year period in remote areas of the world, and since it will involve working with a new riser, blowout preventer, and other recently developed components, special care must be taken to enhance operating efficiency and safety and to minimize damage to the environment. Operating crews must be carefully selected, trained, and qualified. Relief crews, when used, should be similarly trained Also, operating procedures, including contingency plans, should be developed early, and frequent drills should be conducted. Provisions have not been made in either the schedule or budget for accomplishing these tasks.

Critical Design Issues for 13,000-Foot Drilling System

The proposed ocean margins drilling program will probe one of the earth's last scientifically unexplored frontiers, the region of the earth's crust between the continental shelf and the deep ocean basins. This endeavor calls for drilling in ocean depths (13,000 feet) over twice those confronted to date (see Figure 2) and for penetrating beneath the seabed through 20,000 feet (6 kilometers) of sediment. This penetration is still a hurdle in drilling on dry land; achieving this objective in deep water is a major technological challenge. Almost every single element of the entire drilling system will have to have more capability and greater reliability than now available.

As discussed earlier, extensive preliminary engineering studies are needed to meet this challenge and to select the best technical approach for the drilling system. Since such studies may result in some departures from current practices, critical design issues are difficult to anticipate. Assuming that the reliability of field-tested procedures will dictate the use of nearly conventional drilling equipment, the committee selected what appear to be the most critical design issues. Naturally, extensive engineering tests may reveal additional critical issues.

The drilling system comprises a large number of complex and interrelated subsystems and procedures. All of the system elements will probably require some modification from present practices to perform at the extreme water depth and penetration goals of the deep sea drilling program. Table 2 outlines the extent of development in major equipment areas for a deep drilling system. This section highlights a few of the more apparent design challenges that need to be resolved.†

General Requirements

The expected deep sea drilling projects could encounter a wide spectrum of unanticipated problems. Thus, the system will have to be designed to be able to adapt to overcome these problems. For

†Other literature on the topics discussed in this section is identified in the Reference section (references 9 through 18), pages 63-64.

TABLE 2

DEEPWATER DRILLING

TECHNOLOGY/WATER DEPTH SPECTRUM

	To 300-350' WD	To 2000-3000' WD	Today To 4000-5000' WD	To 13,000' WD (Estimated Technology Requirements)
Vessel:	Bottom Founded Jack-up or Submersible	Floater, Semisubmersible or Shipshape →		Large Shipshape (Glomar Explorer) (E)
Vessel Positioning:	Fixed	Conventionally Moored	Dynamically Positioned →	
Riser:	Extended Casing	Bare to 1500' Buoyed beyond 1500'	Buoyed Max. Top Tension: 1 Million lbs.	Buoyed (E) Max. Top Tension: About 1.5 million lbs (D)
		Max. Top Tension: About 640,000 lbs	Storm Hangoff Procedure Desirable	Storm Survival Procedure Necessary (U)
			Multiple Riser Trips Undesirable Riser Handling System Desirable	Impractical• Necessary (F)
				Extension of Depth Capability (E)
Well Reentry	N/A	Guidelines	Guidelineless Remote Re-entry with TV and/or Sonar	
				Requires Stronger Clamps (U) & Connectors(U) and/or BOP Frame (F)
Blowout Preventer	Surface	Subsea - Redundant BOP's →		
	No Remote Control	Direct Hydraulic Control	Multiplex Electro-Hydraulic Control → Subsea Accumulators, Rechargeable from Surface Acoustic Back-Up Control	Subsea Hydraulic Power Source Probably Necessary (U) Extension of Depth Capability (E)
Wellhead Foundation:			Sensitive to Pullout & Side Loads from Riser	Critical (E)
Well Control:	Surface Choke Adequate →	Deepwater Kill Procedures Required →	Pressure Equalization Valve (Available) →	Seafloor Choke for Circulating Gas Kick Desirable (D) Probably Necessary (D)

Key: U - Undeveloped; D - Developed but not field tested; E - Extension of existing technology; F - Field tested

• Solution dependent on casing program and feasibility of extending drilling shallow hole without riser

example, site selection will be based on minimizing the likelihood of encountering pressurized hydrocarbon formations. However, the drilling system must be fully capable of dealing with such an occurrence with complete safety since geophysical data is not completely reliable.

A basic casing program (i.e., a series of various lengths of different diameter tubes), wellhead, blowout preventer, and riser will have to be selected. Deep penetration and the anticipation of numerous well control problems plus the constraint of a minimum core diameter all suggest a large-diameter riser/blowout preventer system.

On the other hand, a large riser is heavy and bulky to handle and incurs great horizontal forces imposed by current and waves. These must be compensated for by the ship and the wellhead. Deepwater drillships now use 16-3/4" diameter blowout preventers and associated riser and wellhead systems. This arrangement permits a maximum of 4 casing strings to be run through the riser starting with a 13-3/8" diameter and ending with a 5" diameter. In this case, the 30" and 20" strings have to be run without blowout preventer protection; this is currently standard offshore operating procedure. The Glomar Explorer may allow for storing and handling an 18-3/4" riser, which would permit running an additional casing string through the riser. Use of the larger riser, however, would most likely involve a more elaborate wellhead system to support the heavier stack and greater loads from the riser.

Drilling for Surface (Structural) Casing

In deep water, drilling with the 30" and 20" casings (and the 16" casing if it is used) is often done without a riser. Prior to setting the 30" casing, however, the riser has no foundation. Even after it is set, the 30" casing is usually not sufficiently founded to support the riser loads alone. A small pilot hole is usually drilled to emplace these larger casings to determine if shallow gas or other geological hazards are present. Nonetheless, in continental shelf waters of the United States and some other countries, regulations require running the riser for all drilling operations after the largest surface casing is set. In 13,000 feet (4 kilometers) of water, it will probably be almost impossible to set a 30" casing capable of supporting the riser loads. Should this occur, the riser may have to be mounted on a pile-founded support on the seafloor, a problem with no precedent in these water depths.

Another way to protect against shallow gas during drilling is to have a packer or downhole blowout preventer in the drillstring. Should shallow gas be encountered while drilling without a riser, the packer can be inflated to shut off the flow. A heavy "kill" fluid or mud mixture can then be circulated behind the packer to set the casing or to cement and abandon the hole. Some development work has been done on such a device, but it is not nearly field ready.

Another problem associated with surface casings is that they are too large to go through the riser. If the riser is run for the drilling operation, it must be pulled while the casing is run into the hole. In 13,000 feet (4 kilometers) of water, this is a time-consuming and expensive procedure. An attractive but untried technique would be to set the riser aside; i.e., have a means of physically moving the riser off to one side, supporting it there, and running the casing into the hole without bringing the riser onboard the ship.

Riser Handling

Handling the riser correctly becomes critical in extreme water depths. For example, deploying and retrieving the riser, usually a simple procedure, may be extremely difficult if there is even a mild current over most of the depth. As the riser is deployed deeper and its sail area increases, it tends to get pushed to the side by the currents.

The requirement for a thorough understanding of environmental conditions that may impinge on design and handling of the riser can be supported by several operational scenarios. Such an example is the almost inperceptable long-period swell conditions to be expected in some areas, such as extreme southern latitudes where major and unpredictable axial loading of the riser can result. Adequate advanced surveys, predictive capability, and monitoring while operating will alleviate such potential problems.

As currently designed, deepwater risers are nearly neutrally buoyant. A variable buoyancy system will probably be necessary to make the riser sink as it is being run, and then made buoyant after it is connected at the wellhead. By so doing, the riser floats upward and assumes a vertical position in the water. Now the ship can disconnect from the riser without losing it.

Moving the vessel away from the wellhead also presents problems. In the event of a severe storm, the ship's safety would be jeopardized if it had to maneuver with a 13,000 foot riser hung from the moonpool. Generally, there will not be enough time to pull the entire riser up and store it aboard the ship. Thus, an upper disconnect platform may be needed several hundred feet below the surface. The riser could be disconnected at this point, with the remainder becoming positively buoyant. This approach has been considered before, but has not yet become operational. Much needs to be done to provide high reliability in the reconnection process. Two important components--an underwater electrical connector and controllable buoyancy--are being developed by industry, but are not fully operational.

Another aspect of riser handling relates to the trade-off between the capacity of the riser tensioning device and the riser buoyancy. The capacity of the riser tensioner will have to be quite large if the riser is not to be greater than neutrally buoyant. Use

of a positively buoyant system would allow a nearly conventional riser tensioning system. However, the latter approach would require developing a highly reliable buoyancy-dumping system to protect the vessel in the event that the riser parted from the ocean bottom connection.

Well Control

In drilling into the earth, a drilling fluid (often termed "mud") is circulated down the drillstring and back up the annulus between the drillstring and the drilled hole. The mud cools and lubricates the drill bit, prevents formation fluids from entering the hole by controlling the pressure at the bottom of the hole to keep the hole from collapsing, and carries the formation cuttings made by the drill up to the surface. The bottom-hole pressure is controlled by variations in either the mud weight (usually expressed in pounds per gallon),† the pressure applied by the mud pump on the surface, or both.

The mud pressure at the bottom of the hole must be:

- Greater than the hydrostatic pressure and the formation pressure to prevent formation fluids from flowing into the hole; and

- Greater than the hydrostatic pressure to provide sufficient velocity of flow back up the annulus to carry the cuttings to the surface; but

- Less than the fracture pressure to prevent "lost returns" where the mud breaks up the formation and flows into it rather than back up the annulus.

A "gas kick" occurs when the drill enters a portion of the formation where appreciable geopressure exists (e.g., because of the presence of gas). When this occurs, the mud weight or pressure must be changed rapidly and accurately to withstand the sudden increase in pressure and prevent a "blowout" or uncontrolled flow out of the formation and up the hole.

Herein lies the basis for some of the major problems with deepwater drilling. When drilling on land (see Figure 4) the hydrostatic and lithostatic pressures increase simultaneously from the same starting point, and the difference between these two pressures continually increases. This provides "room to work" between the two pressures in controlling the well pressure and potential blowouts.

In deep water, however, the lithostatic pressure begins to increase at the ocean floor where an appreciable hydrostatic pressure already exists. Therefore, the hole must be lined with a structural shell or casing for some depth to provide a "spread"

†Salt water weighs approximately 8.56 lbs./gal.

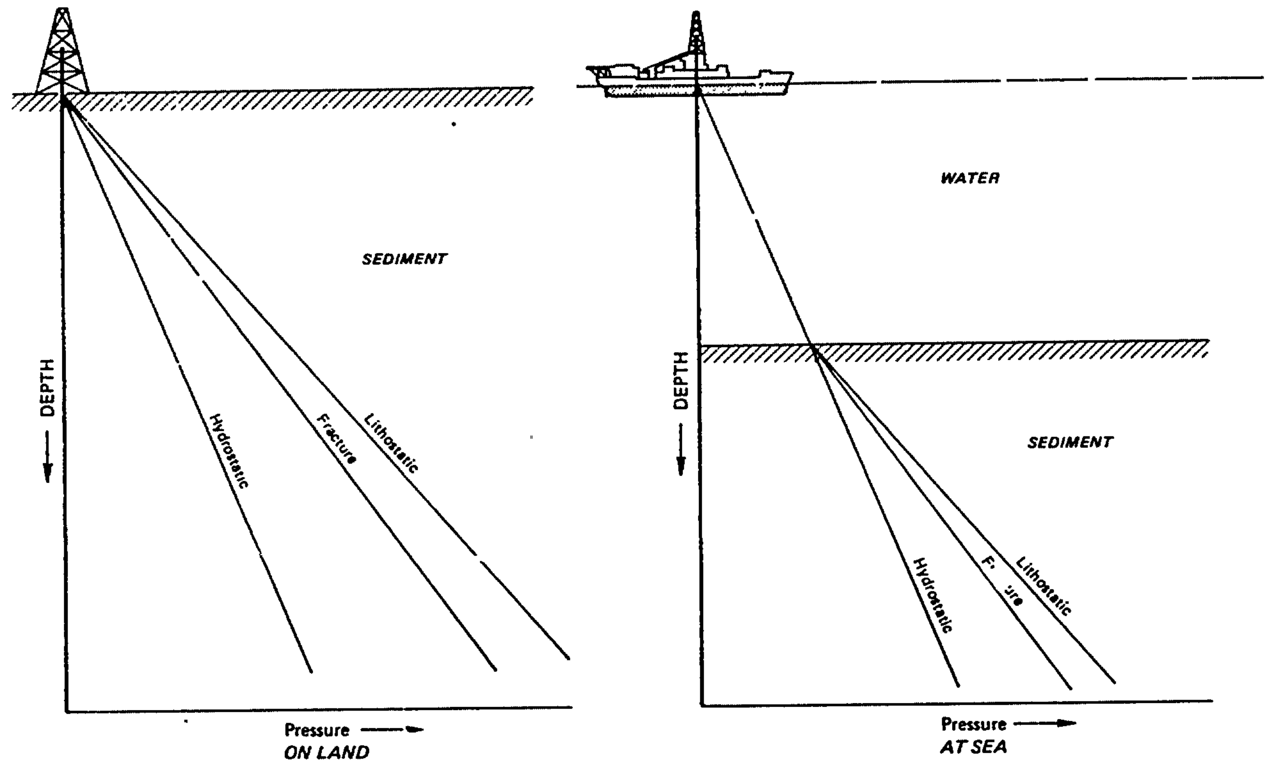

Figure 4 General Relationships among Pressures that are Relevant to Drilling and Well Control

between the hydrostatic and lithostatic pressures so that mud or some other drilling fluid can be used to control lost returns and blowouts. Further, the deeper the water the greater will be the length of structural casing required to provide "working room" between the hydrostatic and lithostatic pressures. The structural casing is also required, of course, to provide a foundation to support the wellhead, blowout preventer, and riser base.

A widely accepted basic rule of safety for drilling is that the drilling mud is the first line of defense against a kick or sudden flow of gas or formation fluid into the hole. In very deep water, much of the mud column required to maintain control is in the riser. If the riser must be disconnected, part of the downhole pressure is lost. In some cases, the mud remaining in the hole is insufficient to prevent a potential kick with systems now in use. Closing the blowout preventers would provide the extra protection required.

With the deepwater system envisioned in this report, the extra protection may eventually be provided by one or more of the following items:

- Downhole instrumentation to provide more immediate surface warning of undue pressure increases, coupled with a pause in drilling to provide time for more precise adjustment of mud weight.

- Deeper or more frequent casing settings.

- A secondary downhole blowout preventer or inflatable packer run in the drillstring that could be activated to seal the hole near the bit.

Since the well control system may need modification to adapt it to deepwater use, the need for intensive pre-engineering to support extensions to deep sea drilling is emphasized.

In any event, the probable greater dependence on the blowout preventer in the well control system emphasizes the need to ensure that the blowout preventer can be reliably controlled. The high cost of pulling the blowout preventer up to the ship for servicing during long drilling operations is sufficient incentive to improve reliability.

A new underwater power supply for blowout preventers will probably be required because the pressure accumulators used in deep water are less efficient.

Circulation of a Gas Kick

The conventional method of circulating a gas kick is to bypass the riser using the choke or kill line (a small-diameter line located adjacent to the riser) and direct the gas flow to a controlling choke (valve) at the surface. In very deep water, this

method is difficult and time consuming because of time lag in the flow through the small diameter line. A constant downhole pressure must be maintained as the gas comes up this small-diameter line instead of up the riser; this is often difficult to do. An alternative technique involves a seafloor choke (valve) that controls the gas flow at the wellhead. A prototype choke has been developed, but has never been field tested.

Drilling and Well-Control Simulators

Computer-based simulators can help prevent blowouts, control wells, and circulate the gas kick. Computer simulations can help check equipment concepts and operational procedures prior to design completion. Although sometimes considered to be simply training aids, they also permit early qualification testing of instruments, control station layouts, and many items of equipment.

Reentry and Seafloor Manipulation

Many drilling rig operations use a manned submersible to land the blowout preventer, to land the riser on the blowout preventer, and to help solve other problems that may occur on the seafloor. Other rigs depend entirely on remote reentry systems and on manipulating devices that can be handled on the end of a drillstring and watched with a remote television camera.

The decision whether or not to use a submersible in the NSF drilling program will affect program time and cost. The decision should be made by the engineering systems contractor during the concept development phase of the program. No manned or remotely controlled submersible now being used can dive to more than half the depth called for by the NSF drilling program.[18]

The development of a submersible could cost $10 million to $20 million and take three to four years to build and test. Operating without it, however, might be extremely costly should seafloor problems cause the loss of a well after many months of drilling. This decision will probably be based on an extensive examination of the operating experience of deep-water rigs.

Blowout Preventer Pressure Integrity and Wellhead Structure

Greater water depths lead to higher hydrodynamic lateral loads on the riser, simply due to its greater profile area. Furthermore, the blowout preventer will probably be taller than those now used, which extend more than 40 feet above the seafloor (see Figure 5). Because of this height combined with the larger riser, the blowout preventer will be subjected to higher loading moments. This could bend the wellhead structure. Higher bending moments will

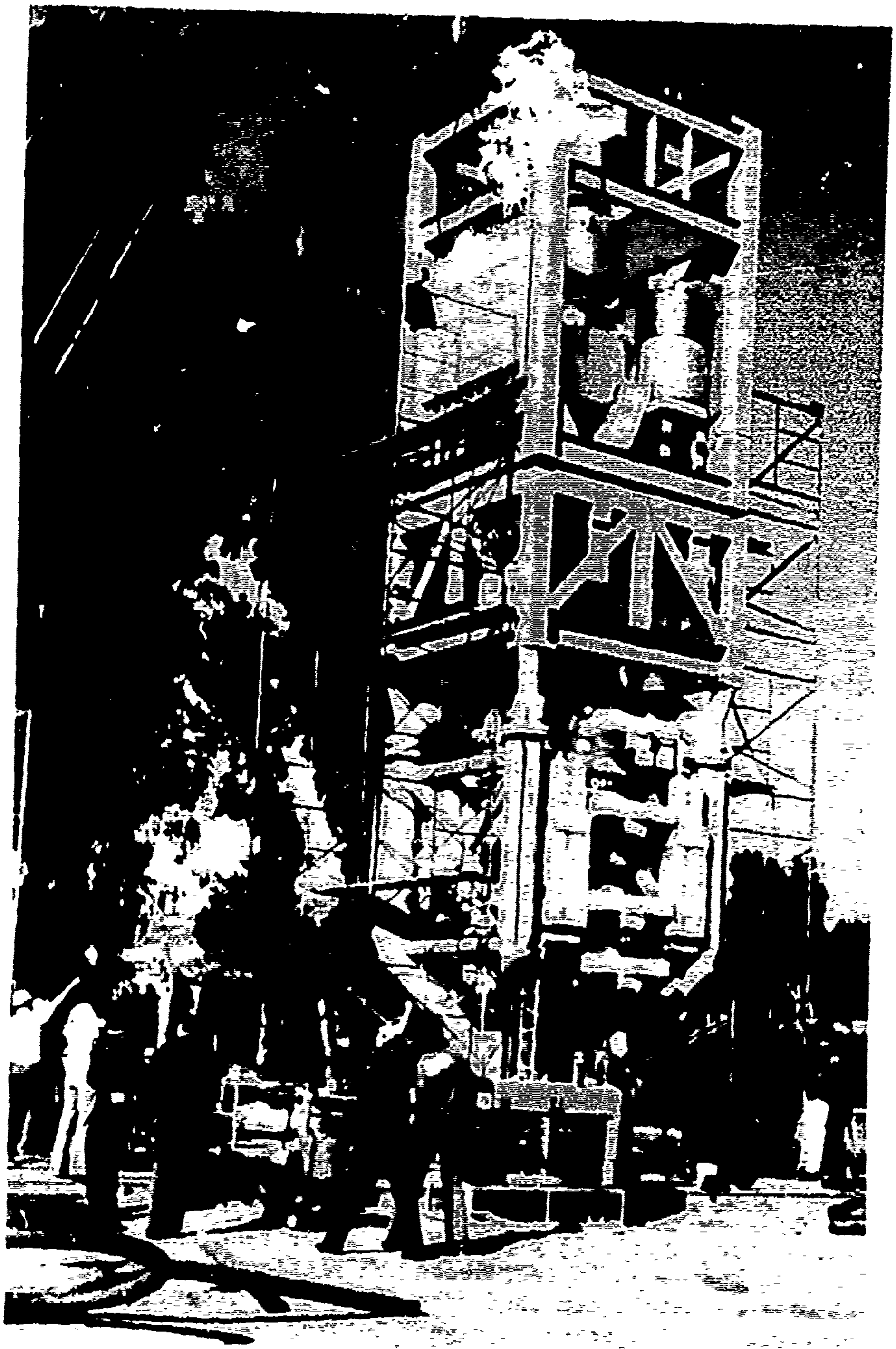

Figure 5 Guidelineless Blowout Preventer Stack System

substantially reduce the ability of the clamps that tie the segments of the blowout preventer together to withstand these loads. These clamps are already marginal at present deepwater conditions, and will have to be strengthened. Wellhead connectors will require upgrading as well.

A careful check of the wellhead structure strength will have to be performed at each new site. It will depend on soil measurements at each site. The high bending moments that must be tolerated will likely require the use of wellhead structures larger than those now used to distribute the load over a broader area. These checks should be made early because of the time needed to design and build special wellhead structures.

Environmental Influences on System Design and Program

Wind, current, seaway motions, and soil conditions on and below the seafloor affect the design and operation of the drilling system. Any one of these elements, or a combination thereof, would prevent exploration, restrict operations to certain times of year, or curtail drilling operations once they are under way. Thus, to plan a scientific program, conditions at any potential drilling site need to be predictable. Also, planners need to be able to calculate the magnitude of the forces applied to the system and to assess how the system will respond to those forces. While there is some environmental information available now that is usable for preliminary structural design, this information at best is sparse and incomplete. Acquiring information for design purposes early in the engineering activity is essential to a safe and effective program.

Engineers need to know the range of environmental conditions that will affect a drilling system over its lifetime and how often the system will be exposed to conditions of varying magnitude. The system can then be designed to withstand the expected forces up to the point where the cost of critical system elements exceeds the scientific benefits to be gained. Sites where the environmental conditions exceed the engineering capabilities of the system must then be deleted from the scientific program, or the program with respect to those sites must be curtailed because of engineering constraints.

Each potential drilling location should be examined and analyzed to determine whether the goals of the science program for that site are technically feasible at reasonable costs. Also, the schedule of the operation should be set to coincide with a reasonable set of environmental conditions. Site selection and scheduling must therefore be an iterative process, beginning at the earliest possible date. It should include measurements of wind, current, sea motion, and other forces and analyses of their effects on drilling

system components now in use or being designed. This may lead to design changes in new system components, upgrading of existing components, or rescheduling or curtailment of the operations at a selected location.

Obviously, it costs too much to measure the environmental forces at every possible drilling location. However, because of the long time and expense of drilling in passive margins where a riser is required, it may be economical, even imperative, to provide a complete environmental survey for each selected site. Available oceanographic data can be examined to determine sites to be tested where the most severe conditions can be anticipated from a list of tentative drilling sites. Moreover, it may not be necessary to measure all the forces at each site. Rather, only those elements that pose major design or operational problems need to be measured in detail.

Measurements need only be sufficient to establish the magnitude of a specific force as it affects the design or operation of the drilling system. Measurements should be made in such a way that the results can be used directly in making engineering analyses of the forces that will act on the system.

Wind

Winds in the general location of a proposed drilling site are of interest for two reasons. First and foremost, winds can blow the drilling ship off station and damage the system, or even lead to the drilling operation being abandoned. Secondly, wind-generated waves, swell, and eventually surface currents, can impede or even endanger operations.

The force applied to a ship is proportional to the square of the velocity at any given altitude multiplied by the differential projected area of the ship at that altitude. The vertical integration of these differential forces constitutes the total force applied. Therefore, in making wind measurements it is desirable either to obtain velocities at a number of levels above the ocean surface or to provide a device that measures the integrated force over a distribution of area that represents the ship itself. This can be reduced to a few simple measurements as long as the overall complexity of the system is recognized. Measurements of wind force on the Glomar Explorer itself coupled with wind velocity measurements at a few vertically separated points would provide a reliable basis for selecting the profiles to be measured in the site survey operations.

The force imposed on the ship by the wind will vary with wind direction relative to the ship. Maximum force will be developed by a wind at 60° to 70° off the bow or stern and minimum force for a bow-on or stern-on wind. However, the direction of the maximum force will not necessarily align itself totally with the wind

direction because of the complex nature of wind flow around a superstructure. Determination of the force distribution with wind angle is important since it will not always be possible to head the ship into the wind if a seaway is running, if a strong current is acting on the underwater body, or if forces are being imposed by drifting ice. If the ship is allowed to move off station, or if the wind force is being opposed by a current force, it is also possible for a turning moment to develop.

To counteract wind forces and moments, an equal amount of thrust force and moment must be applied by the transverse thrusters and by the main propellers. Adequate power must be used to develop the required thrust to counteract the forces imposed by the wind. This, in turn, requires the ship to be designed with minimum superstructure area. Nevertheless, the wind force calculations cannot be made final until the superstructure design is known.

Current

The magnitude, direction, and duration of ocean currents at potential drilling sites must be known with some precision before a ship and riser system can be designed and before any site can be selected for drilling operations using a riser. Of primary importance are the maximum daily cycles of current velocity and direction from the surface to the bottom. In other words, data must be collected for all currents over a long enough period to be able to predict conditions for the scheduled drilling operation.

For those sites where riserless drilling is planned, only surface currents need be measured since the primary forces involved are those that will be imposed on the ship hull itself. However, before the current measurement program is so restricted, a determination is needed as to whether lift or drag forces are a potential problem on extremely long drillstrings in a current flow. If they become a problem, a complete current profile should be obtained for riserless drilling sites as well.

For practical purposes, a typical current profile does not exist for any given area of the ocean. Nowhere is velocity and direction of current completely constant from the surface to the bottom. In all areas, there are both horizontal and vertical circulations with no fixed relationship. Therefore, current magnitudes will vary in a random manner with regard to both depth and lateral position, and current direction will also vary randomly and may rotate through 360^{o} several times between surface and bottom. The best summary that can be obtained is derived from spectral analyses of the current magnitude at different depths for a series of overlapping time periods. The maximum energy density of these spectra plotted against depth will be most useful in designing riser pipes.

The technique of measuring currents and recording the required data over long time periods is well advanced. Since these data are so critical to the system design, data gathering should begin immediately at all locations where riser drilling is planned. This will not only provide essential information for the design of the riser, but may also permit full evaluation of alternative sites at an early time if necessary.

The forces applied by surface currents to the hull of the drillship can be calculated with reasonable accuracy as a function of current direction and ship draft. A power allotment for the thrusters and main propellers can then be made to compensate for these forces in the same manner used to counteract the wind.

The forces on the riser pipe should be calculated for several possible configurations. It is possible that fairings* will be required on parts of the riser to reduce the drag coefficient from about 1.2 to 0.2 to 0.3. If fairings are used, they should be of the variable-direction type because the direction of current flow will be neither constant nor predictable.

The force distribution along the pipe will determine whether it can stand free and be disconnected at the surface or whether it must be disconnected at the seafloor if the ship is forced to leave its station. The force distribution will also determine what loading and bending moments will be placed on the seafloor connection and on the ship itself. These factors also will influence the overall design of the system and determine whether riser drilling is feasible at a selected site.

Once feasibility and design of the riser have been determined, the magnitude and distribution of the current forces on the resulting configuration will dictate how and when the operation will be conducted. Thus, the early acquisition of current profile spectra at riser drilling sites is probably the most important environmental force consideration in the pre-drilling period.

Ocean surface motion, combining swell and sea, usually results from the affect of high velocity winds of relatively constant direction on the water's surface. Generally, sea is related to local winds whereas swell results from winds that have previously disturbed the surface in distant areas. Thus, if the winds are of relatively constant velocity and direction in a given area, the wave motions will follow the same directional pattern. Swell, on the other hand, may move in a different direction than the local winds and waves. Furthermore, more than one swell pattern may move across a given area of the ocean.

Reducing of roll by heading into the seas is not always feasible. In cases where the directions of swell and waves do not coincide, or when two swell patterns are coming from different directions, a satisfactory heading may be unattainable. Or, when trying to minimize resistance to wind or current, broadside or quartering seas may be unavoidable. The Glomar Explorer responds minimally to roll, even to beam seas, because of its extremely

*Refer to Glossary.

broad-beam configuration. Furthermore, the ship is equipped with a passive anti-roll tank stabilizing system and a derrick motion-compensation system that can significantly reduce the bending moments applied to drillstring and riser due to roll motions.

The motion-compensation system reduces the effects of heave accelerations on a suspended load. To date, it has coped with any seaways to which the ship was exposed whenever a large load was suspended from the derrick. However, there are limits to the combination of roll and heave motions that can be compensated for when some of the loads anticipated in deep sea drilling are applied to the derrick and to the motion-compensation system. If, for a selected drilling program at a given site, these limits may be exceeded, then either the program must be altered or another site found.

A number of factors must be considered to make this evaluation. These include the amplitude and frequency characteristics of the seaway motions at a given site, the response of the ship in roll and heave to the motion of the sea, the characteristics of the motion-compensation system, and the anticipated critical system loadings during the drilling program.

First, long-term data should be obtained on the sea conditions at each prospective site. Essentially the data needed are energy spectra of the seaway motions. Once the data are available, the ship response must be predicted. Models of the Glomar Explorer have been tested to see how it would respond. Additionally, the ship itself has instruments both to measure the motions of the seas in which it operates and the response of the ship to these motions. An investigation and evaluation of this data should be launched in the near future.

Finally, the derived maximum ship motions must be examined in light of the known characteristics of the motion-compensation system and the anticipated characteristics of various designs of drill-string and riser systems. These results will affect the design of the drilling system as well as the feasibility of operation at a specific site. This again points out the need to get the site selection and data-measurement programs underway as soon as possible.

Bottom Conditions (Seafloor and Shallow Subsurface)

The character of the ocean floor sediments must be known to depths of 100 to 300 meters below the bottom. This is required to properly design and install the surface casing that forms the primary foundation for the wellhead, blowout preventer, and riser bottom attachment. This equipment is being developed satisfactorily. Often, the required *in-situ* measurements are made on-station just prior to drilling. For this program, however, as much information as possible is needed quickly on the sediments at the proposed drilling sites to help design equipment and planning operations.

Before drilling commences and to ensure optimal use of the drilling equipment, a testing system that can evaluate the sediment characteristics (i.e., civil engineering properties) should be devised to determine the capability of the seabed sediments to support a hole. New testing procedures or compound-test hardware may be needed to simplify the time-consuming techniques now used.[19]

Bottom Conditions (Deep Subsurface)

Before either scientific or commercial drilling can begin, the geophysical characteristics of the layers below the seafloor must be assessed by adequate reconnaissance. Such exploration can normally delineate the broad structural features of the surveyed area and can help planners select where to drill.

Using seismic reflection techniques, reconnaissance surveys can penetrate the crust to almost any depth and obtain a fairly wide range of information. However, costs rise as deeper penetration and more information is sought.

Early in a continental margin drilling program, the geophysical equipment used to explore the bottom can help select broad areas in which useful information can be gained by drilling and coring. When a specific drill site must be chosen, however, a site survey must be performed using the best state-of-the-art exploration techniques.

Drilling on the continental margins entails an appreciable risk of encountering geologic hazards like unstable bottom or near-bottom sediments, deposits of hydrocarbons, and active fault zones. Any of these could cause the drilling program to fail. In addition, the program may not meet its goals if the drill penetrates an unexpected or anomalous section.

Seismic reflection techniques used by commercial drillers can identify anticipated hazards in most areas with a reasonable degree of confidence. What will generally be required is a closely spaced grid of reflection lines surveyed with equipment recording 100-or-more channels of data and with at least a 24- or 48-fold data-processing multiplicity (redundancy). Processing should include the production of acoustic-velocity-transform sections to detect hydrocarbon deposits and over-pressured zones. Three-dimensional processing may be needed in areas of complex structure.

If the site to be surveyed covers the practical minimum area of 4 to 10 square kilometers, the cost will probably range from $225,000 to $1 million per site. Sites in high latitudes or in other areas with severe logistical problems can entail substantially higher costs. Such costs should be evaluated in comparison with the substantially higher cost of drilling.

Summary

Both reconnaissance and closely-spaced grid geophysical surveys should be undertaken early to determine those sites where the desired scientific information can be obtained with minimal geologic hazards and maximum chance of successful coring.

The next step is to explore the bottom conditions in the selected locations to determine those sites with the most favorable properties to support the foundation structure. At this time, civil engineering data would also be obtained that would affect the design of the riser, and the seafloor and casing system. As shipboard analysis indicates satisfactory bottom conditions, a current-meter string can then be implanted together with wind and wave measuring equipment. Data on these factors should be obtained over an extended period of time (a year or more) to provide the system design guidance; this information is particularly important for design of the riser and well control system, which is essential in areas where hydrocarbon deposits may occur. Since the well control design and construction process may require several years, it is vital that such environmental site-specific data be acquired early in the program.

Equally essential is the acquisition of wind and sea data and vessel response characteristics for the drilling platform.

Operational Safety, Environmental Impact, and Personnel Training

The proposed deep sea drilling will be conducted, with full well control, in unprecedented water depths with incomplete soil, current, wind, wave, and other information. It will employ equipment, in some cases still undergoing development, that must achieve capabilities that greatly exceed current practice. Prudence dictates that extra precautions be taken to safeguard personnel, prevent technological failures, and protect the environment.

Deep sea drilling that uses blowout prevention and a drilling riser in very deep water will impose physical requirements on some of the equipment that are greater in magnitude than at present. For example, the wellhead and foundation structure will have to absorb forces and bending moments that are much greater than those absorbed by present equipment. Further, as noted in earlier sections, the margin for error in some activities--for example, changing mud weight to control the well--will be much smaller.

In addition, personnel will have to be trained, detailed procedures developed, and new types of bottomhole and seafloor instrumentation used to continuously sense well control parameters.

Therefore, safety panels must review the specific procedures appropriate to the platform and drilling site and recommend standards and requirements that should apply in each case. These will differ from the regulations cited in Appendix C for offshore commercial drilling, in view of the considerations of water depth and specialized equipment. Clearly, there is heavy dependence on the blowout preventer and on conservative, well-planned procedures to maintain well control.

Drilling Vessel Safety

In converting the Explorer for use as a drillship, NSF and its contractors will have to comply with the Coast Guard Rules for Mobile Offshore Drilling Units (Title 46 of Code of Federal Regulations, Subchapter I-A). The Coast Guard should be consulted to determine how this subchapter applies to the Explorer.

For international operations, it may be sufficient to comply with the International Maritime Consultative Organization (IMCO) Code for the Construction and Equipment for Mobile Offshore Drilling Units.

The entire drilling system, including the drillstring, riser, blowout preventer, wellhead, casing program, mud program, cement, etc., should comply with the United States Geological Survey's Order No. 2., "Drilling Procedures," for the outer continental shelf (OCS) operations. In addition, each foreign nation's rules and regulations (petroleum directorates, etc.) should be identified and complied with for drilling in their waters.

If hydrocarbons are encountered, drilling operations should comply with USGS-OCS Order No. 3, "Plugging and Abandonment of Wells." USGS-OCS Order No. 7, "Pollution and Waste Disposal," covers regulations to protect the environment. An early evaluation and decision should be made as to whether the equipment needs protection in case hydrogen sulfide (H_2S) is encountered.

Environmental Protection

The environmental impact statement (EIS) being prepared by NSF should reflect the system design limitations and operational procedures. A risk analysis must be included in the process.

Risks

Because the proposed drilling program is in some respects unique, environmental risks must be projected on the basis of experience to date with Glomar Challenger and with commercial drilling with risers in shallower water. Normal operations appear to present no significant environmental impacts.

The primary concern is blowout during drilling. This could result from suddenly encountering high pressure in the drill hole or from loss of control of the riser during a storm together with the presence of high pressure in the hole. From June 1956 to June 1979, 85 blowouts have occurred in oil and gas operations on the outer continental shelves of the United States. Of these blowouts, 17 released some oil or condensate. Two of these are considered minor spills and one a major spill (Santa Barbara). Three occurred while drilling.[20,21,22] Outside of U.S. waters, the recent Ixtoc I blowout in the Gulf of Mexico appears to have released some 3 million barrels of crude oil.

Site selection for scientific deep sea drilling should be specifically aimed at avoiding formations likely to contain petroleum under pressure. On the other hand, losing control of the riser may be more likely than with commercial drilling since the scientific program goes beyond the present state of commercial practice.

Loss of fluids - Fluids lost during normal drilling operations will include formation waters from the structures being drilled, fluids lost in the processing and recovery of drilling mud, and the ship's normal wastes. Formation waters may include brines and other waters rich in dissolved salts and gases. Fluids from the drilling muds may contain heavy metals and bactericides.

Loss of solids - Solids lost will include cuttings from the well and suspended solids lost when reprocessing drilling muds. The composition and volume of these can be estimated from experience in commercial offshore drilling for petroleum. When drilling with a riser, disposal presumably will be at or near the water's surface. This will disperse both the cuttings and the fine solids from the muds, depending on water depth and currents at the drilling site.

Impact on the pelagic ecosystem - Both solids and liquids will kill some marine organisms, especially plankton. Plankton are small, often microscopic marine plants and animals that form the base of the ocean food cycle. They are relatively sensitive to small changes in their environment. While not all plankton species will likely be affected to the same degree, not enough is known about how plankton react to the substances that may be released into the waters to predict which ones will suffer most. These effects should be relatively short lived and limited in extent by dilution of the affected water through eddy-diffusive processes.† Ocean life should recover quickly once drilling ceases and water currents bring in fresh recruits from nearby, unaffected areas.

Impact on the benthic ecosystem - Most bottom environments in the deep sea have very slow rates of deposition of sediments, high diversity of species, very slow growth of individual organisms, and a mixture of mobile and attached or slow-moving organisms.[23] The immediate area around the wellhead, or any area in which more than approximately one centimeter of cuttings accumulates, will be depleted of many species of the fauna, especially meiofauna and other infauna. Because bottom fauna grow and reproduce slowly, recovery could take from 100 to 1,000 years, depending on depth and the extent of the impact.

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†The time required to detoxify any given body of water might be modeled as a function of the required dilution factor, volume of water, and the coefficient of eddy-diffusion.

Recovery will be very slow at any site deeper than 1,650 feet (500 meters), and it will be exceptionally slow at depths in excess of 16,500 feet (5 kilometers). The area affected by drilling will be small (e.g., .1 square mile) relative to the very large range (e.g., 20 million square miles in the Pacific) of bottom-dwelling organisms. Therefore, so far as we know, drilling does not threaten the survival of species as such.

Overview of the impact of normal operations - Thus, normal deep sea drilling for scientific purposes appears to be environmentally acceptable. Those impacts that will result are highly localized and widely spaced. They are far enough from shore to present no threat to living reefs, banks, or other shallow areas of special interest or sensitivity. The impact on marine organisms will be transitory. The impact on the bottom community will be localized, albeit long lasting.

Types of Impacts in Mishaps and Accidents

The two types of mishaps that seem most likely to occur would result from storms and blowouts. The former are probable, since deep drilling will keep the ship on a site for months, during which time it will be necessary to cope with storms. Routine procedures include releasing and recoupling the riser to prevent loss of well control. Blowouts occur rarely, even in commercial drilling for petroleum.

Loss of riser and drillstring - If a sudden, severe storm should blow the ship off its drill site with the riser still connected to the ship, the riser and its contained drilling mud and cuttings could be lost. The ecosystem would be affected about the same as a ship sinking in deep water. After the loss of a riser, the wellhead would have to be relocated. Drilling could be continued with a new riser system, or the hole could be plugged. The technology exists to do this. However, this would require that a back-up riser and blowout preventer be available at all times. While loss of the riser would pose no threat to the ocean ecosystem as a whole, it would be a continuing threat to local organisms.[24]

Blowout of gas and brine - In addition to the impacts caused by a severe storm, a blowout could contain gas, possibly including hydrogen sulfide (H_2S), and saline formation waters could escape into the water. Although there are tidal and other currents in the deepest part of the ocean, there is relatively little vertical mixing of water because of the effect of temperature and salinity in a column of water. Complete vertical mixing requires on the order of 1,000 years.

Therefore, anything introduced into the water near the bottom will tend to remain there at a level determined by its density. It would also tend to spread out in a thin, long-lasting layer in the

water. If this were toxic, it would decimate the organisms over a rather extensive area of the seafloor. However, there are areas where this is happening naturally today with no evidence of major impact. For example, hot brine has been released together with sulfides as a result of active volcanoes on the seafloor near the Galapagos Islands.[25] This release has apparently resulted in only very localized toxicity. Similarly, a release of petroleum in the Atlantic Ocean 400 miles (650 km) off Venezuela has produced a widespread hydrocarbon-rich area with no demonstrated toxicity.[26]

Blowout of petroleum - A petroleum blowout is the least likely but worst case. The Ocean Margin Drilling Program is not intended to explore for oil or gas. Present plans call for drilling to be discontinued if substantial hydrocarbons are found in the core, especially in the presence of geopressure.

There is no experience with a blowout in the deep sea. If a blowout did occur, it would probably cause a layer or layers of the effluents to spread out in the deep water and remain for at least several decades. Studies show that organic matter lasts longer at great depth because the bacteria that break it down are less active than they are in shallow water or on land.[27,28,29] Moreover, the volatile and relatively toxic fractions, as well as the highly toxic aromatic, water-soluble fractions, would be wholly contained in the water. Toxicity in the deep sea probably would be greater and last longer than with blowouts in which most of the crude oil is initially at or near the surface of the water.

Because a blowout is a possibility, albeit remote, in deep sea drilling, the blowout preventer becomes more important as the final line of defense. Thus, contingency plans for blowout response, developed specifically for each drilling site, are even more desirable than for operations in shallow water. These plans should take into account:

- Proximity to land;
- Local and regional hydrography;
- Availability of containment booms and other cleanup equipment, if appropriate;
- Season and weather;
- Geophysical survey data and other equipment; and
- Operating and well control procedures.

The contingency plan should be reviewed by the site selection and safety committees. Any change in site would require revision of the plan. Both basic and site-specific contingency plans are vital to proper training of personnel, discussed later in this section.

It must be assumed that, in the worst case, it would be necessary to relocate the well and drill an adjacent well to intercept and plug the first one. A continuing, unchecked blowout on the seafloor would have an unacceptable environmental impact. Existing seeps are not believed to constitute a comparable pertubation of the environment.

Safety Procedures

Both from the viewpoint of successful completion of the scientific mission and of general safety for personnel, the drillship, and the environment, accident prevention is of paramount importance. Drilling programs should be developed for use in design and in environmental protection planning. For the latter use, it should be conservative, carefully monitored and managed, and should include specific safety-oriented drilling, blowout preventer, and well control procedures. The present guidelines are general ones, because there will be considerable variation in actual practice, depending on conditions at each site and equipment used.

Drill-Site Selection

The procedures used to select drilling sites for the deep sea drilling program, including committee reviews and specific guidelines, appear to have worked well. The policy avoids sites where significant quantities of hydrocarbons are likely to be encountered. For drilling in deep water with a riser, it may be advisable to avoid sites where there is a probability of high geopressure, with or without hydrocarbons.

Drilling Procedures

Drilling may have to be stopped if, in the judgement of the drilling supervisor, there is unacceptable risk of an accident, especially one in which loss of well control is possible. Decisions to terminate will be influenced by many factors, including weather and currents, water depth, fracture gradient, the extent of downhole instrumentation, and the extent of well control at the seafloor.

When using risers longer than those now available, additional instrumentation at the seafloor and in the hole may permit work to continue in the presence of marginal relationships between weight of drilling fluid in the riser and the fracture gradient of the rock. Sensors in the hole might include a pressure transducer,* an electromagnetic kick detector,* and a scintillation counter. The latter could rapidly indicate loss of drilling mud by detecting naturally occurring or added gamma emitters in the mud. These instruments are being developed, but are not now available.

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*Refer to Glossary.

Well control on the sea floor now consists of a blowout preventer stack. Some modification in the basic design of blowout preventers will probably be necessary for work at great water depth. In addition, it will probably be necessary to vent gas kicks at the blowout preventer level and to minimize problems of circulating gas out of a very long, small-diameter choke line. These are discussed in the earlier section on critical design issues.

In addition to obtaining more and better scientific data, advanced downhole instrumentation may well provide valuable information to help decide when to terminate or continue drilling at any particular stage of the or .tion.

Contingency Plans and Simulators

In addition to contingency plans for dealing with blowouts, they are equally or more important for preventing blowouts. These plans should be integrated into drilling procedures. They should be developed and tested using a computer-based drilling and well control simulator, as discussed in the section on critical design issues. Such simulators are not only extremely useful in designing the well control equipment and instrumentation systems, but they are also invaluable aids in developing procedures and contingency plans as well as training personnel.

Two such simulators should be provided. One should be on land to help plan and design the program and to analyze problems. The other should be on board the drillship for use in operational and contingency training and for quick on-site analysis of problems as they arise during operations.

Personnel Training

Highly trained personnel will be required to operate the drilling program because of the special nature of deep sea drilling that requires special techniques for use under conditions not normally encountered by the drilling industry. The drillship should be staffed with the very best-qualified and motivated personnel to ensure minimum turnover. In commercial drilling, extensive training for the crew and use of frequent safety drills are standard. They are even more important in deep sea drilling where new technology and equipment is being used in great water depths.

Initial crew training should include formal instruction, possibly of several weeks duration, and extensive use of the drilling and well control simulator for both routine and emergency procedures. Drills, safety reviews, and checks should be done often enough to minimize human error if an emergency arises.

Early training is of paramount importance for those, like the drilling supervisor, who occupy critical positions. Critical positions should be identified during the equipment design phase,

and should be filled prior to completing the design. Those who fill these positions would not only be better trained from having "lived with the equipment" throughout its final design, fabrication, testing, and installation, but they would also contribute to the design. The advisability of using this concept was also noted in the section on schedule and budget.

Equipment Qualification

Testing - Because the program involves new or extended equipment and new systems, they should be tested and proved qualified prior to being used. The riser system, which probably will be new or modified from existing designs, should be used first under the most favorable general conditions of weather, water depth, and ocean currents. The same approach is advisable for modifications on the blowout preventers and downhole instrumentation.

Also, operating instructions and maintenance manuals have to be written with the utmost care, so they will be effective and used routinely.

Special Equipment Redundancy - Because some of the equipment will not be easily replaced, attention should be given to stocking spare or back-up equipment for critical items. In view of the possibility, however remote, of having to drill a relief hole in case of a blowout, consideration should be given to ordering duplicate risers, blowout preventer stacks, and drillstring.

In addition, many components must be supplemented by other devices to increase the entire system's reliability by allowing it to continue to operate when the "primary" component fails or functions improperly. A typical example is the provision of both acoustic and inertial position-reference equipment.

Coring and Coring Technology

The ultimate purpose of a scientific drilling program is to acquire cores of as good a quality as possible. Geophysical and logging techniques may furnish much valuable information, but the cores constitute the principal product. This section discusses some of the requirements and constraints of the coring program that should be considered with the development of all other components of the proposed drilling system.

Even before Glomar Challenger left on her maiden voyage in 1968, various scientists realized that undisturbed cores, high recovery rates, and, more often than not, continuous coring would be necessary to achieve many of the primary objectives. It appears doubtful that continuous coring will be feasible in the deep penetrations sought by NSF. Tradeoffs in time, cost, alternate data-gathering techniques, and achievable penetration need to be considered carefully.

Current Status of Deep Sea Coring

Although high quality cores and continuous sediment coring have been the goal of deep sea drilling programs for many years, the record of achievement is still mixed. The most recent 15 legs (ship tours) have cored approximately 75 percent of the total depth penetrated. As stratigraphic analysis has shown, however, "continuous coring" does not produce continuous cores. T. C. Moore demonstrated with data from the first 20 legs that even presumably continuous coring retrieves only about two-thirds of the total sequence.[30]

The mean core recovery over the years has been about 50 percent and is highly dependent on lithology, being as low as 25 percent in chert-bearing sediments. Core disturbance, although difficult to quantify, has been high. On leg 40, for example, 60 percent of the length of the core was disturbed, and 15 percent was severely disturbed.

Considerable improvement is needed in both the quality and recovery of deep sea drilling cores. The newly developed hydraulic piston corer has provided a dramatic increase in quality and recovery in sea trials. Whether it loses the same amount of core between trips remains to be determined.

However, the hydraulic piston corer functions only in unconsolidated sections in the upper few hundred meters of geologically young deposits. For older and deeper deposits, and particularly for the deep sections to be cored in the proposed very deep drilling program, the problem remains unsolved. A program to develop better continuous coring techniques should be given a high priority by NSF.

Coring Needs for Future Drilling

While the problem of acquiring high quality cores from sediments below a few hundred meters is unsolved, it is not unsolvable. Adequate attention should be given to developing appropriate tools for coring deeper than 657 feet (200 meters), the limit of surface coring devices. This should be done in the design and construction phases. NSF should recognize that the best drilling system, riser, and platform will be only as good as the information provided by the cores the system is designed to obtain.

At the present time, scientists tend to think in terms of continuous coring. In the deep penetrations under consideration, the cost and time of coring become major factors. In fact, the cost of coring becomes eventually equal to all other costs. Planning will, unlike in the past, have to include coring schedules as a key element in both the design and operational phases. Intermittent coring supported by appropriate logging seems inevitable, and its use must be made optimal.

Development Requirements for New Coring Systems

No system or piece of equipment now being developed or adapted from ones now in use will likely solve all the potential problems. What is greatly needed is a well designed and supported effort to develop new coring techniques. The following items should be considered in the planning (see Appendix D).

Bits - Conventionally, new designs are based on finding suitable cones from smaller bits to mount around the coring throat. Generally, however, larger cones have better bearing capacity. Thus, a 12-1/4" bit should be designed using either 9-7/8" or 10-3/4" cones. These should not be difficult to develop, but manufacturers have shown little interest so far. Although not a serious problem, the planned extended runs require attention to cutter life, including the use of drag elements of diamonds or new materials.

Positive Control of Bit Load and Torque - To control bit load and torque in coring in any crystalline rock, a downhole mechanism must be developed. This control is essential to obtaining high quality continuous cores and is vital if diamond core bits or polycrystalline diamond bits are to be successfully used. Use of an advanced heave compensator is also mandatory.

Early contacts and liaison with appropriate bit manufacturers can help alleviate problems and assure timely development and delivery of the needed special bits on schedule. In addition, these development efforts should be strongly supported by comprehensive laboratory tests and evaluation. This should help assure an optimum use of the time at sea.

Instrumentation - Instrument packages are needed to acquire information during or subsequent to drilling. Some of the measurements will be of interest primarily for scientific purposes whereas others relate more to the drilling process. The importance of these measurements to the program should be assessed.

Parameters of interest include temperature, porosity/density, permeability, shear strength in-situ, and acoustic velocity, among others. Although instruments are available for some, adaptation to hole diameters, operational depths, and other parameters are necessary in some cases and improved design is needed in others. Since it may be necessary to deviate from continuous coring, the requisite instrumentation assumes major importance and needs careful and adequately supported advance planning, design, and development.

Drilling Related Measurements - Since coring may be required at small diameters (7-7/8"), drilling parameters may have to be measured at or near the bit. Assessments are needed on the usefulness of information on weight on bit, acceleration, inclination, penetration rate, and differential penetration rate.

Coring in Oceanic Basement

During the recent phase of NSF's deep sea drilling program, a considerable effort has been expended on crustal drilling on mid-ocean ridges. However, the results have been unsatisfactory because both penetration and core recovery have fallen short of scientific requirements and expectations. Through leg 64 of the program, basement drilling had penetrated to a maximum depth of 1,910 feet (582 meters)--on leg 37, a depth never again matched. The average core recovery was 14 percent; 21 percent of the results of leg 54, which had a particularly low recovery rate, is omitted.

In addition, many of the most important sites on recently deposited oceanic crust are buried under less, often considerably less, than the required few hundred meters for spudding.

This commonly leads to poor recovery, frequent sticking in the hole, and loss of bit and other important equipment. Young oceanic crust consists of piles of pillow basalt. These piles alternate with thick accumulations of thin sheet flows resembling, according to observations from the submersible *Alvin*, stacks of broken glass consisting of jagged fragments of all sizes and thicknesses from a few inches to several feet. In addition, the sheet-like flow formations contain extensive open lava tunnels and caverns that apparently persist to considerable depth below the seafloor.

No proven technology now exists to solve most of the problems associated with drilling in these pillow basalts and sheet flow (pahoehoe) formations. The belief that the availability of full circulation would mitigate most if not all the problems, except spudding on young crust, is probably not justified in view of the extensive presence of large cavities and the nature of the sheet flows. Experience in coring in Hawaiian lavas exists and should be consulted. On the whole, however, the problems of drilling into the ocean crust will not be solved without an innovative, determined, and well-supported development program complete with field experiments.

ALTERNATE PROGRAM PATHS

In line with the general conclusion that there is no substitute for hands-on samples of deep-earth rock in reaching the scientific objectives, the need for a deep ocean platform to drill and core the sediments is obvious. In its interim report, the committee examined the use of submarine, semi-submersible, and shipshape floating platforms for this program. It concluded that a large shipshape vessel was the most viable alternative.

Although certainly some of the target sites could be handled with semi-submersibles, they lack the capacity to accomplish all the program's objectives. For instance, the advisability of drilling from a semi-submersible platform in ice-prone areas was seriously questioned. In addition to the technological requirements, there are other essential features of a large shipshape that argue in its favor.

First, ships possess large storage capacity for essential material and supplies. Adequate facilities are also needed for an efficient scientific laboratory to handle, analyze, and test cores. Money and time could also be saved by closer coordination between core testing and drilling operations.

Further, scientists can use the ample space of a ship to install instruments to obtain a full spectrum of oceanographic and operational data. They would have access to data-processing facilities. Finally, of all the platform types, the drillship can best move quickly from port to a drilling site or from one site to another.

Explorer - In examining the possibilities for a feasible platform for deep sea drilling, the Glomar Explorer can be converted to a highly desirable vessel capable of satisfying all the technical and support demands of the program. Further, since the vessel's cost has already been largely written off and the conversion costs appear reasonable, the Explorer would reduce initial capital investment for a drilling vessel.

As already mentioned, there is no semi-submersible on the horizon that can meet the demands of the deep sea drilling program as described by NSF to the committee in September 1979. Thus, such a vessel would have to be designed and constructed from scratch. Further, since it would probably not be usable for other purposes, the full amortization of a semi-submersible's capital expense would accrue to the project.

Drilling-System Development

As noted in essentially all the engineering studies NSF has sponsored, the state of deepwater drilling technology needs to be extended from its presently proven 5,000-foot (1.5 kilometers) capability to the desired 13,000-foot (4 kilometers) capability. Depending on the details of the scientific program planning, alternate paths can be considered for this extension: immediate conversion of the Explorer, interim use of a leased commercial drillship, and interim extended use of the Challenger.

For example, the scientific program requires the use of riser drilling fairly late in the program and only in water depths of 10,000 to 13,000 feet (3 to 4 kilometers). Hence, one logical path would be the direct development of a "new" 13,000-foot system for the Explorer. This development (and the required ship conversion) should be preceded by thorough and detailed engineering analyses and studies.

On the other hand, the scientific program might require relatively early riser drilling in water depths of about 6,500 feet followed by gradual increases to the ultimate 13,000-foot goal. In this case, riser drilling should begin with a (leased) available commercial drillship that has a proven 5,000-foot capability and potential 9,000-foot capability. The leased ship and system could then provide a "test bed" or "proving ground" to guide and support the development of the ultimate Explorer-based 13,000-foot system. In either case, the conversion of the Explorer to accommodate the 13,000-foot drill system should not be undertaken until approximately two years of engineering work has defined the system in much greater detail.

As an alternative to converting the Explorer early in the program, the Challenger could accomplish much of the planned riserless drilling and thereby provide greater schedule leeway for the required engineering studies. As noted in the section on budget and schedule, using the Challenger beyond its presently planned extension through 1980 could attain most of the planned riserless-drilling goals and thereby provide much-needed time to properly engineer the Explorer system.

Consideration of these and other such alternate paths should be undertaken early in the program in conjunction with, and parallel to, the development of the more-detailed scientific plan.

Geophysics

Although seismic surveys cannot be entirely substituted for actual cores from deep sea drilling, they can be used to help acquire information and insight on the continental margins. Because the program envisions only a small number of cored wells, the project should use the most highly sophisticated, modern seismic technology to survey specific sites to plan drilling.

Coring and logging information can then be used to calibrate the seismic data to better understand the subsurface in the non-drilled areas. This may require some additional fine-grid seismic surveys during the specific site surveys. In this way, the cores and well logs from the drilled wells can be used to interpret seismic surveys throughout the control region with greater confidence in the validity of the data. This area of expertise, particularly in reflection seismics, will have to be acquired under contract with commercial organizations; no adequate capacity exists in the academic community.

INTERNATIONAL IMPLICATIONS AND TECHNOLOGY TRANSFER

In planning for the continuation of deep sea drilling on the continental margins, a matter of concern will be international negotiations for access to both the 200-mile economic zone and to other areas of questionable jurisdiction. While the *Challenger* program has been able to cope well with this problem, aspects of the *Explorer* program may pose new issues.

In the first place, NSF wants to include the Departments of Energy, Interior, and Commerce in its deep sea drilling program. This certainly raises the possibility of differing views on international involvement. The very nature of the continental margin drilling objectives, where hydrocarbon potential exists, increases the potential for conflicts among cooperating nations. At this stage the committee itself sees no specific basis for concern, but feels additional study is required as program planning proceeds. In any event, avoidance of hydrocarbon-bearing structures should be emphasized in international arrangements.

Information Acquisition and Development

Technological capability beyond that currently possessed by industry will likely be required. This capability may have to be developed at the expense of the program. What then are the vested interests of the various contributing partners in this advanced technology? This question undoubtedly will be treated more fully as the program develops, but its implications for both industrialized and developing nations needs to be resolved.

Of even greater potential concern, the *Explorer* program could be extended to detect, identify, or determine the potential for finding natural resources in the drilling areas. What assurance can or will NSF give the various participants for guarding the vested interests of each nation? Will the presence of other governmental agencies, such as the Departments of Energy and Interior, alter negotiations with cooperating nations?

The committee cannot answer these questions now, but does not feel that U.S. interests will be unduly jeopardized by freely sharing all information developed by the program in the open literature. Some committee members feel that the greatest concern is that of securing for all concerned the maximum input to the world data and information bank. In this regard, the nature of the scientific program is such that it cannot directly determine what the potential for resources is. It can only define ocean basin characteristics in a way that could guide independently organized resource surveys. Any discovery of new resources as a result of the scientific program, as currently defined, would be accidental and, in fact, a mistake, because hydrocarbon-containing structures are to be avoided in selecting drilling sites. As was the case in recommended international arrangements for site selection, on-structure drilling for hydrocarbons should be avoided if industry support of the program is to be encouraged.

Although continuing Law of the Sea negotiations will influence the problems to be encountered in ocean drilling over the next decade, no one can foresee at this time all of the possible ramifications of these deliberations. However, if the knowledge-gathering goals of the program are kept uppermost in all negotiations, cooperation will be greatly enhanced.

The transfer of technology to other countries is one of the more sensitive issues of a program such as this. The committee sees no real threat to the well-being or self-interest of the United States by normal demands for scientific information or technical knowledge.

While the technological requirements of the Explorer program are more advanced than current industry practice, it is not beyond the state of the art. The program thrust will be to accelerate the time it takes to turn research results into industry practice. Much of this know-how is already widespread internationally and need not cause concern or pose any impediment to proceeding with the endeavor.

International Science and Technology Transfer

The committee sees no major problems in this area in view of the prior experience of NSF with many international science programs. There will, of course, be some spin-off of technology from deep sea drilling. As contributions to resource exploitation, most of these will be long-term ones, whose practical application will come, if ever, in the next century. Not only because of international participation, but also because of freedom-of-information considerations, much of the technological and geophysical information will be in the public domain. Industrial participants, if any, might gain short-term proprietary rights to some innovations. In any case, only the active participants will gain first-hand operational experience with the hardware at sea, and that is one of the keys to successful exploitation of new technologies.

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Domestic Technology Transfer

Drilling research and development is almost entirely the province of industry. Just as the first decade of NSF's deep sea drilling program was built on existing technology with innovative modification, so will the ocean margins drilling program be an extension of existing technology. It must be built on that existing base, and in one way or another the relevant industries must be closely involved at every step in the program. The primary technological goal of the program is to extend drilling capabilities into deeper strata under deeper water. It is important that all extant knowledge be available during design, and that innovations coming from the program be disseminated. In this regard, the Department of Energy is a central repository from which extant information may flow and to which new information may be channelled. Information may reach the various elements of the drilling industry through that route, as well as by direct interaction between industry and the program.

As noted earlier, most of the information developed by the program must be disseminated in compliance with the Freedom of Information Act. New developments that may be used in the program can, of course, be protected by existing patent laws with government use provisions for items developed with government funding.

CONCLUSIONS

The objectives, costs, and schedule of deep sea drilling for scientific purposes continue to be uncertain as discussions regarding industry and foreign support and program priorities continue. Because of this, the committee has based its evaluation on the scientific plan that is summarized in this report. In particular, it has focused on the technical objectives of the program: to drill ultimately beneath 13,000 feet (4 kilometers) of water and to penetrate down to 20,000 feet (6 kilometers) beneath the seafloor. Based upon its deliberations and collective experience, the committee reached the following conclusions on the engineering considerations for the continuation of NSF's deep sea drilling program for scientific purposes:

- Substantial engineering development--particularly in well control--will be required to extend the state of practice in some vital areas of deep sea drilling. Given appropriate resources and adequate time, no insurmountable technological, safety, or environmental barriers exist to achieving the drilling objectives proposed by NSF. Industry participation in the hardware development will be essential to program success.

- A comprehensive, preliminary engineering study is critical to the successful development of the drilling system. This effort must include thorough evaluation of alternative engineering approaches, definition of design areas with potentially high technological risk, identification, construction, and testing of critical components, and preparation of comprehensive specifications for the systems integration contract.

- The presently planned period of 12 to 15 months for preliminary engineering studies is insufficient preparation before commitments are made to convert a ship, or acquire a platform, and to construct a drilling system.

- Normal deep sea drilling operations for scientific purposes appear to have a slight, localized, and transitory effect on marine organisms, and a longer lasting, although still

local, influence on the bottom community. The major concern is possible environmental damage from a petroleum blowout, even though this is considered an unlikely event. While there is no experience with a blowout in deep sea, if one did occur, the oil would spread in deep water and would remain for years because bacteria that decompose petroleum are less active in deep water than near the ocean surface.

- Despite the explicit NSF policy to avoid drilling in high-pressure hydrocarbon-bearing formations, the emphasis on investigating passive margins dictates an ability to handle abnormal geological pressures and unanticipated hydrocarbons. Achieving the capability and reducing risk to people and the environment will require extensive design and development effort, contingency planning, and personnel training.

- NSF's current budget for the program appears to be low. It omits additions to Explorer's capability to keep its station, gather environmental data, acquire and train a crew, and perform detailed site-definition geophysical surveys. It also makes inadequate allowance for monetary inflation (projected by NSF at 7 percent per year).

- Adequate geophysical surveys are required before drilling sites are selected. Such surveys will involve a general broad-based geophysics program followed by detailed surveys for site selection and safety purposes. The geophysical conditions and environmental conditions--winds, waves, currents, and seabed engineering characteristics--need be ascertained at specific sites and analyzed before and during the system engineering effort. Further environmental measurements are required in concert with all phases of the drilling activity.

- Scientists expect their principal gain to be the acquisition of high-quality cores. Current technology is inadequate to provide consistent high-quality cores. Although no engineering breakthroughs appear necessary, early development work will be required. Because the cost of coring becomes very high at very deep penetrations, coring and coring schedules must be balanced against alternate data-gathering techniques, cost effectiveness, and how much penetration can be achieved.

- With some modification, the Glomar Explorer is the most feasible platform to conduct the program. Here too, however, much more engineering work must be accomplished prior to converting the Explorer. Further, the ship and its crew and equipment must be treated as an integral part of the complete drilling system.

- NSF must exert ultimate program control over contractors during the development, testing, and operational support phases of the science program. This requires an ability to evaluate and reconcile technical conflicts as well as to serve as the government focus of science, industry, and international support for the program.

RECOMMENDATIONS

The committee developed several specific recommendations for NSF action in its proposed continuation of deep sea drilling for scientific purposes. These recommendations are ge rally couched in terms of the use of Explorer and the goals of p netrating 20,000 feet of sediment at water depths of 13,000 feet. Despite this, the committee considers essentially all recommendations to be equally pertinent to other possible platforms and drilling penetration or water depth goals. Accordingly, the committee recommends that NSF:

- Establish a strong management team to control and guide the program and to maintain close industry contacts to ensure that the required technology is developed. The team should be part of the NSF staff. It may be supplemented by contracted engineering personnel competent in offshore drilling (as discussed in Appendix B).

- Operate the program and develop the equipment using a systems-engineering approach (as outlined in this report and Appendix B).

- Allocate adequate time and funds for a thorough preliminary engineering study of at least two years duration prior to coverting the ship or fabricating any major equipment.

- Give early attention to the major critical design issues of the drilling system--well control, riser handling, and casing programs.

- Review and modify the budget to include the cost of additional equipment, data gathering, acquiring and training a crew, and geophysical surveys, and to take account of current monetary inflation in preparing cost estimates.

- Increase the effort devoted to collecting and analyzing as much meteorological, oceanographic, and ocean-floor geotechnical data as possible for engineering design use, covering the broad geographic areas of concern to the

program. Moreover, this effort should be extended as early as possible to acquiring similar data for specific, smaller areas as the site-selection process narrows the areas under consideration.

- Adapt existing and develop new logging and downhole measurement equipment to improve the safety of drilling operations and to lessen the scientific impact of the anticipated reduction in core recovery from deep penetration.

- Include funding for improved coring equipment and techniques for sedimentary and igneous rocks in the initial system design and development effort.

- Give early attention to personnel recruitment and training, so that key operational personnel can help design and develop both equipment and procedures. This includes the concurrent development of computer-based drilling simulators for initial use as design aids and training tools and for later use for problem-solving and continued training.

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GLOSSARY

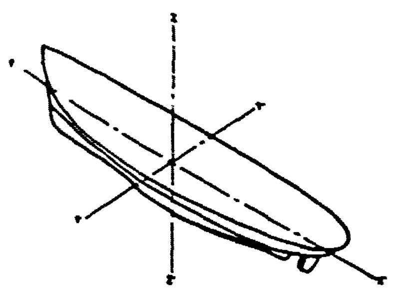
Blowout Preventer (BOP) A large metal assemblage of valves and flow passages that serves primarily as a shutoff device to prevent the escape of unwanted flows of gas or fluids from the well (see Figure 5 for an example). The blowout preventer also serves as as the primary structural attachment point for the riser.

Bottomhole Pressure The pressure that exists at the bottom of the drilled hole under the conditions that exist at any particular time.

Casing String A series of heavy metal tubes that are larger in diameter than the drillstring and bit. The casing diameters decrease in steps as additional lengths of it are extended below the ocean floor. The large diameter upper sections serve primarily as the structural foundation for the wellhead, blowout preventer, and riser base. All sections of the casing string serve as a liner of the drilled hole to prevent collapse of the hole or leakage of drilling fluid into the foundation in regions above the bit. It also prevents leakage of formation fluids and gases onto the surface through the lined portion of the hole or into other formations of lower pressure.

Core A cylindrical portion or sample of the rock or sediment into which one is drilling.

Degree of Freedom The movement of a ship is classified into degrees of freedom or motions:



Roll - a transverse inclination, or tilt, about the longitudinal (xx') axis.

Pitch - a longitudinal inclination about the lateral (yy') axis.

Yaw - lateral inclination about the vertical (zz') axis.

Heave - vertical, linear motion (rise and fall) along the (zz') axis.

Sway - lateral, linear motion along the (yy') axis.

Surge - longitudinal motion, forward and astern, along the (xx') axis.

Drillstring and Bit A long tubular member made up of joints of thick-walled metal tubing. At the lower end of the string there is a "bit" or cutting tool that, when rotated, cuts through the sediments and rocks of the earth. The hollow center of the string provides a flow path for the drilling fluid or mud and a passage for coring tools used to obtain and recover long cylindrical samples of the material through which the drilling is done.

Drilling Fluid A fluid that is pumped down the drillstring to cool and lubricate the drill bit, control the pressure at the bottom of the hole, and carry the cuttings from the drill bit back up to the surface. Drilling fluids are usually water- or oil-based solutions or suspensions of chemical compounds that are referred to as "muds," and which may be varied in "weight" or density to aid in controlling the well pressure. Mud "weights" are normally expressed in pounds per gallon (U.S. gallon), and range from 8.3 lbs./gal. for salt water up to more than 15 lbs./gal. for some special compounds.

Drilling Platform A ship or other structure that provides support, storage space, handling gear, and operating equipment for drillstring, riser, and other elements.

Dynamic Positioning A system wherein the ship or other drilling platform will be equipped with motion sensors and computer-controlled thrusting devices that resist the forces of winds, waves, and currents to maintain the platform in the proper location over the drilling site.

Fairings A member or structure (or addition to a structure, e.g., addition to a cable) whose primary function is to reduce the drag or resistance to the movement in water or air.

Formation Pressure The pressure that exists within the geological formation. Its value usually lies between the values of hydrostatic and lithostatic pressure.

Fracture Pressure The pressure required to fracture the rock or sediment structure of a geologic formation.

Hydrostatic Pressure The fluid pressure at the bottom of the hole (see Figure 4). This pressure increases with depth at a rate of about 1/2 lb. per sq. in. per ft. depending on the density of the fluid.†

†Hydrostatic pressure per ft. - 0.433 psi for fresh water, 0.444 psi for salt water, 0.34 psi for "light" crude oil, and 0.41 psi for "heavy" crude oil.

<u>Kick; Kick Detector</u> A sudden pressure increase in the borehole of the well with a resulting influx of gas or fluid into the well. This pressure and flow must be detected immediately to allow necessary adjustment of the well control system--e.g., mud weight or flow, blowout preventer action, or chokes (valves).

<u>Lithostatic Pressure</u> The pressure applied by the weight of rock in a column equal in height to the depth of penetration of the drill (see Figure 4). This pressure increases with depth at about 1 lb. per sq. in. per ft. for typical rocks.

<u>Logging, Well</u> The process of measuring various characteristics of the formation through which the hole is drilled. Various instruments are lowered into the hole to measure resistivity and radioactivity, among others. The measurements are recorded at the surface.

<u>Mud</u> See Drilling Fluid.

<u>Pressure Transducer</u> A device actuated by the surrounding gas or hydraulic pressure in the hole, that supplies an electrical signal to a gauge or monitor on the surface.

<u>Riser</u> A long tubular member that is situated around the drillstring and extends from a supporting and tensioning device on the ship or platform to the ocean floor. The annular space between the drill string and riser provides a return passage for the drill fluid and for the "cuttings" that the bit removes as it drills into the earth.

<u>Seismic (Geophysical) Measurements</u> A method of investigating the structure of geological formations by propagating sound waves into the earth and recording the times of arrival of reflection (or echoes) at the surface.

<u>Wellhead</u> A heavy metal assemblage of flow passages that is located on the ocean floor and provides the basic support for the casing strings and for attaching the blowout preventer to the structural casing.

APPENDIX A

Contributors To The Report

During its meetings and deliberations, the committee was assisted by information and advice provided by the following:

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Alfred S. Arcache, Triton Engineering Services

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APPENDIX B

PROGRAM MANAGEMENT: DRILLING-SYSTEM PROCUREMENT CONSIDERATIONS

The committee regards the drilling system for the Ocean Margin Drilling Program to be advanced technology, and an undertaking having technological risk. Control of that risk is possible only with a systematic and carefully planned development program. In carrying out programs to develop advanced technology, military and the space agencies have evolved procedures intended to maintain close control over cost and schedule while maximizing the likelihood of achieving the desired capability. The National Science Foundation should consider using these techniques to develop the deepwater drilling system. To illustrate the way these techniques can be applied, several of the key steps are summarized in this appendix.

The problems related to major system procurement are basically the same in government as in industry. The discussion in the text, (page 19) regarding one company's experience in an analogous situation reinforces the need for a systematic well-staffed capability present within NSF to manage the procurement of the drilling system. The industry based example in the text was a smaller step in technology compared to the proposed deep sea drilling program; in addition, the company had two years of preparation without facing uncertainties in design objectives (compared to various science operational requirements) and did not face government reviews and approvals.

The deepwater drilling system is roughly defined by its subsystems, as given in Table 3. Although preliminary and somewhat simplified, this breakdown encompasses the system's key elements.

Perhaps the two most important facets of advanced technology project control are preplanning and project management. Major cost and schedule overruns occur when unexpected problems are encountered during the fabrication and operational phases. The more time and effort that is devoted to prefabrication studies, the greater is the likelihood of avoiding major unexpected problems. Although preliminary studies delay system start-up, they are relatively inexpensive and often reduce time lost to later delays. The preliminary study period provides time to gather all the relevant engineering information, explore various technical approaches, and organize the personnel to manage the development and operation.

TABLE 3

Major Subsystems and Development Components of a Deepwater Drilling System

- Blowout Preventer Control System
  - Downhole Blowout Preventer†
  - Seafloor Choke†
  - Subsea Power Source for Blowout Preventer Operation†
- Casing Strings
- Cement (Bulk Storage, Mixing, and Pumping Equipment)
- Coring System
- Derrick, Travelling Block, and Motion Compensator
- Drillfloor (Rotary, Driller's Station, Drawworks, etc.)
- Drilling and Well-Control Simulator
- Drilling Instrumentation
- Drillstring System (Drillpipe, Drillbit, Kelly, Downhole Blowout Preventer, etc.)
- Manned Submersibles or Remote Controlled Vehicle for 13,000-Foot Water Depth†
- Mud System (Fluid, Shakers, Pumps, Choke, etc.)
- Riser and Diverter System Blowout Preventer
  - Controlled Riser Buoyancy†
  - Emergency Disconnect and Extreme Weather Disconnect System†
  - Riser Gas Lift System†
- Riser and Drillpipe Handling System
  - High Capacity Riser Tensioner†
- Subsea Instrumentation
- Vessel Station-keeping System
- Well Logging System
- Wellhead
  - Wellhead Instrumentation†

†Systems or Components not in current practice.

A strong and comprehensive project management office is essential. It should be set up at the earliest date to assure continuity and a sense of ownership from the conceptual stages through the development and into the operational phase.

Finally, various so-called "systems engineering" technqiues should be used. These include reliability analysis, failure modes and effects analysis, and critical path schedule analysis. While not all such methods may be applicable, they are techniques intended to assist in controlling the development of complex, advanced technical systems.

Program Management

Ultimate responsibility for development and operation of the drilling system resides in NSF's program management office. This responsibility can be suitably carried out only if the program office has adequate authority and staff to maintain centralized control. For the ocean margin drilling program, or any major development program, the authority will stem from the program office's ability to coordinate and implement the objectives of the scientific community and those of the other program participants.

In addition to the technical review and oversight function, the project management office is responsible for cost and schedule control and system integration. The system integration function may be assigned to the prime contractor. Like the technical oversight function, the program office should maintain an independent control authority if it is to anticipate impending program deviations.

System Development

Many engineering tasks must be accomplished to assure sound schedule and cost projections and a sound technical program prior to final budget decisions, construction, and operation contracts. At least two years will be required for this engineering effort rather than the 12 to 18 months that NSF presently envisions. At the onset, and critical to the effort, is the need to mobilize technical and managerial talent to conduct the program effectively. NSF already has access to qualified advisory groups in both the scientific and engineering areas and has engaged an engineering support contractor. With the assistance of these advisory committees and contractor, NSF must devise and define in detail, the system to be used. This preliminary engineering effort will include:

- Specifications for each element of the drilling system, some of which are outlined in Table 3, including specific acceptance test requirements and procedures for integrating the system. This will include drilling platform modifications.

- Provision of equipment and definition of procedures to assure safety of personnel and protection of the environment while attaining the scientific goals.

- Plans for recruiting and training operations and support personnel.

- Schedules for drilling consistent with the scientific goals and priorities, engineering development, and program budgets.

- Developing means, both organizational and procedural, for interested nations to interact with the program, as well as assuring adequate protection of national interests.

- Identification of satisfactory contractors for the accomplishment of the above objectives.

- Provision of adequate contract administration and legal support.

- Early acquisition of environmental data needed to establish criteria for both the drilling schedule and the system design limits.

The development of a strong program management team and many of the preliminary engineering and planning tasks must be completed before a realistic budget projection can be established and probably before the total program can be approved. Implementation of the program, which will ultimately be contracted out by NSF, can lead to cost overruns and schedule slippage unless close control is exerted by the NSF program management.

Those responsible for conducting the program must delegate the authority to manage the industrial work to a prime systems integration contractor selected by standard RFP procedures. However, program management must retain the authority to review and approve technical schedule, and cost decisions relating to both the scientific and engineering effort.

As the agent for NSF, the prime (or egrating) contractor will eventually obtain other subcontractor. to design and fabricate the system. Other contractors will also be needed for the day-to-day operations of the drilling platform and rig, and for overall logistics.

NSF will need to assemble a qualified sta'f that has or hires a prime contractor with expertise comparable with that of the operating teams. Some of this NSF staff may be acquired on a temporary, or leave basis, from industry, as a possible alternative to relying only on a large permanent NSF organization. An imbalance in program management capability and effectiveness is probable

should NSF not be able to acquire this capability. Further, the composition of the government team must reflect the fact that while the primary objectives of the program are scientific, the major emphasis of the early program will be engineering. In the late stages of the program, engineering problems will lessen and the science objectives will dominate. Consequently, the needs of the management team should reflect this shift with provision for the scientific needs.

Evolution of Alternative Conceptual Designs

The preliminary engineering study begins with a survey of the general approaches that might be used to conduct the deepwater drilling operation. This study should not be limited to field practice, but should include some new and untried approaches. In parallel, the system mission, constraints, and environments should be thoroughly defined. For the deepwater drilling system, this wil' probably involve the derivation of one or more site-representative scenarios that embrace the more difficult combinations of tasks that the system will be called to perform. These would also include certain emergency procedures such as controlling a high pressure kick or coupling with a drive-off during a well control situation.

Development of a general drilling program statement, is the initial approach that must be taken in mission definition. Much greater depth of detail relative to potential drilling sites will be required before the process of evolving conceptual designs can begin in earnest. Those factors of mission requirements that will dictate drilling system design include:

- Geographical location of drilling sites;
- Time of year when critical drilling operations will occur and length of time on station;
- Water depths at drilling sites;
- Bottom penetration anticipated;
- Subbottom geophysical characteristics;
- Anticipated core characteristics and coring requirements;
- Potential for pressurized structure penetration;
- Current distributions, including velocity and direction, from bottom to surface during anticipated drilling periods;

- Wave and swell heights and directions; and

- Wind velocities and directions.

Whenever possible, the environmental data should be developed in statistical form.

An active program must be instituted early in the conceptual design phase to assemble the maximum amount of data on these sites. There should be an ongoing program to collect additional environmental and other site-specific data as the design program progresses. The data should be collected in such a form as to derive a number of mission scenarios that cover the gamut of combinations of performance requirements under which the drilling system is expected to perform. Then, in turn, a conceptual design will be formulated with capabilities to meet each set of performance requirements.

Constraints are imposed by the current state of technology in riser drilling offshore. This technology has not yet advanced to the point that will be required by the ocean margin drilling project. Yet, it is essential that, prior to an attempt to extrapolate current technology to advanced conceptual designs, a thorough state-of-the-art review be made so that all available knowledge will be incorporated to improve the chances of success. Those conceptual designs that involve equipment or techniques already proven to be of doubtful reliability, or those that call for an excessive amount of advanced development, must be eliminated from further consideration.

Since this program will involve both government furnished equipment and informati n, NSF should define the equipment in great detail and provide the information that accurately represents the vessel performance characteristics under all operating and environmental conditions to which it will be subject. These characteristics become a set of constraints that bracket the conceptual designs and eliminate some that might otherwise be feasible.

Through analysis of each concept, in light of environment demands and the other constraints, the selection will gradually narrow down to a limited number of practical design approaches to the mission.

An important consideration here is preconception. Based on their experience, drilling contractors who have put together and operated deepwater drillships might be the most likely candidates to develop conceptual designs. However, contractors tend to extrapolate their own approach to advanced capability requirements. To maximize the probability that the best conceptual designs will emerge, it may be desirable to engage several experienced companies to develop, and attempt to evaluate, their own approaches.

Establishment of Criteria for Ranking Conceptual Designs

In the early part of the preliminary engineering work, a weighted set of ranking criteria should be established for the conceptual designs. These will serve as guidelines in the conceptual design evolution and ultimately will be the basis for choosing the best conceptual design. If the conceptual design work is being done on a competitive basis by several companies or several teams, these criteria will serve as "the game rules." Furthermore, establishing and weighting these criteria force the program office, in conjunction with the scientific community and the program participants, to arrive at an explicit definition of the program goals and their relative value.

Examples of ranking criteria are:

- Procurement time;
- Technology risk;
- Safety (environmental and personnel);
- Potential for future expansion;
- Normalized operating costs; capital cost, and operating cost, including provision for reliability, maintainability, and availability;
- Core quality; and
- Core productivity rate.

Refinement of Conceptual Designs

From the preceding step, relatively few combinations of elements are expected to emerge that appear to be reasonable concepts. They will:

- Meet the established mission requirements;
- Employ the best available drilling platform;
- Withstand the environmental demands over the anticipated periods of scheduled drilling;
- Provide adequate system safety; and
- Lie within a reasonable extrapolation of existing technology.

Although each conceptual design may meet these criteria, there will be many uncertainties as to cost, development time, and technology risk. To reduce these uncertainties, it will be necessary to refine the conceptual designs to the point where more detailed engineering evaluations can be made. This kind of refinement might best be carried out through a competitive procedure with two or perhaps even three engineering companies being involved. An alternative, of course, is to have teams within the NSF program office. In either case, the objective is to develop sufficient engineering data, through analysis and low-level testing, to give reasonably high assurance that the highest ranked conceptual design is really the best and also that cost and development schedule estimates are realistic.

A major outcome of this study may be the identification of additional critical components requiring further development. To avoid having the entire system development schedule dependent on the successful development of a single component, the program office should undertake to develop and test the most critical items on an independent basis. Such work might be contracted directly with an interested manufacturer or through an experienced research laboratory.

Conduct Development Projects for Critical Components and Gather Data for RFP Package

Early in the conceptual design phase or even prior to it, certain essential components of the deepwater drilling system will be identified as critical potential impediments to the system development. Some of these may already exist in industry as prototypes. As soon as such components can be identified and the required specifications developed, the program office should initiate a development program. In some cases, manufacturers will probably be enthusiastic about continuing an existing development program with government assistance. In other instances, it may be necessary to initiate the component development (See Table 3) with a manufacturer or through a research laboratory.

In anticipation of preparing the RFP for the system design, fabrication, and integration, extended environmental measurement programs may be necessary. Although the conceptual designs will be evaluated on the best information available, better information is needed for the final design and acceptance testing. The kind of information described in a typical drilling program should be gathered on a continuing basis during the preliminary engineering studies.

Preparation of Bid Specification Package for the Systems Integration Contractor

The final step in the preliminary engineering process is preparation of the bid package for the systems integration contractor. This package forms the basis of the program office's contract

with the prime contractor. It incorporates all of the insight and engineering information that the program office developed during the previous steps of the preliminary engineering studies. The degree to which it anticipates and avoids development problems and the extent to which it spells out the prime contractor's responsibilities will determine the success of the fabrication, integration, and startup activity. If the package contains major areas of ambiguity or uncertainty, these will almost inevitably turn into cost and schedule problems. If the specifications are not explicit in defining acceptance criteria for the drilling system, the system may not achieve the expected capability. Even the most conscientious contractor may not meet the customer's expectations if they are not fully and explicitly defined.

Not only must the bid specification package convey the scientific mission requirements and the design and operational constraints and environments, but it must also tell the prospective contractor precisely how to demonstrate that the system being designed will conform to these requirements. The package should contain clearly defined incremental deliverables such as engineering analysis material, material processing specifications, and component and subsystem tests. Review of such interim information by the program office should provide warning of impending performance deviation well before the risk of major cost overruns.

In the package, the potential contractor will be provided with the specifications of the selected conceptual design. There will likely be a few areas in which the contractor will be expected to conduct additional tradeoff studies among competing approaches, perhaps even some additional development on components or subsystems. In such cases, the contractor should be requested to clearly define in the proposal how to carry out that development and to estimate cost and schedule. In such cases, especially, the specifications package should contain explicit criteria for acceptable performance.

Following are some of the essential elements of the bid specification package:

- Scientific purpose (mission requirements);
- Complete specification of government-furnished equipment;
- Reports of preliminary design studies;
- Conceptual design specifications;
- Performance requirements--capability, reliability, maintainability, and availability;

- Operating manuals and documentation;
- Logistics support requirements;
- Anticipated development schedule;
- Requirements for preliminary and final design reviews;.
- Intermediate and final component, subsystem, and system acceptance requirements;
- Environmental data; and
- Reporting requirements.

Procurement and Startup of the Deepwater Drilling System

The program office must evaluate and select the best respondent to the RFP. The selection process may well involve negotiation with prospective bidders. Undoubtedly, some bidders may consider some of the conditions in the bid specification to be beyond reasonable expectations or may find areas of technical disagreement. In final negotiations with the prospective contractor, the program office should arrive at mutually acceptable terms with the contractor. These may well result in a modification of the specification package based on the bidder's insight and experience. This is a critical phase because at the end of negotiation, the selected contractor is committed to the requirements of the specification.

Almost always during the development period, the prime contractor will encounter unexpected difficulties and will request contract modifications. In such cases, further negotiation will be necessary. The ability of the program office to minimize deviations from the mission goals will depend on how closely its technical staff can follow and guide the prime contractor. Similarly, no matter how much attention is paid to writing the acceptance test requirements, there will undoubtedly be areas requiring judgement and interpretation. Again, the availability of technical staff to support the program office by conducting independent analyses will determine how closely the prime contractor can be controlled.

The final steps in the procurement procedure are as follows:

- Selection and negotiation with a prime contractor;
- Preliminary and final design review and acceptance;
- Component and subsystem acceptance testing;

- Fabrication and integration of the system;
- System acceptance testing; and
- System startup.

APPENDIX C

Letters from U.S. Coast Guard and U.S. Geological Survey
Regarding Offshore Drilling Regulations

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

MAILING ADDRESS
U S COAST GUARD (G-MVI-1/TP24)
WASHINGTON, D.C.
PHONE: 202-426-1464

16703
1 August 1979

Mr. Donald W. Perkins
Assistant Executive Director
National Research Council
2101 Constitution Avenue
Washington, D.C. 20418

Dear Mr. Perkins:

This is in response to your letter of 5 July 1979 in which you requested the Coast Guard to identify the present and probable regulations applicable to the GLOMAR EXPORER and its conversion to a drill vessel.

The GLOMAR EXPLORER is currently being operated with a U.S. Coast Guard Certificate of Inspection issued in accordance with Subchapter I - Cargo and Miscellaneous Vessels in Title 46 of the Code of Federal Regulations. The vessel holds current Cargo Ship Safety Construction, and Safety Equipment Certificates issued under the provisions of the International Convention for the Safety of Life at Sea, 1960.

If the vessel is converted to a research drilling platform, the appropriate regulations will become those contained in Subchapter I-A - Mobile Offshore Drilling Units. The regulations for electrical engineering, marine engineering, load lines, pollution and rules of the road requirements will remain applicable. Within a year it is anticipated that the International Convention for the Safety of Life at Sea, 1974 will supersede SOLAS 60. The changes will not have any appreciable impact on the operation of the GLOMAR EXPLORER.

Questions concerning the application of specific requirements should be addressed to the U.S. Coast Guard Officer in Charge, Marine Inspection, 165 North Pico Avenue, Long Beach, California 90802.

Sincerely,

J. E. DeCARTERET
Captain, U.S. Coast Guard
Chief, Merchant Vessel Inspection
Division
By direction of the Commandant

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

In Reply Refer To:
EGS-Mail Stop 620
CD-292

JUL ; :'9

Mr. Donald W. Perkins
National Research Council
Assembly of Engineering
2101 Constitution Avenue
Washington, D.C. 20418

Dear Mr. Perkins:

Your recent letter requested our assistance in determining present and probable regulations that would be applicable to a deep sea drilling program for scientific purposes.

While operating on the United States Outer Continental Shelf (OCS), the U.S. Geological Survey (USGS) would be the primary enforcer of regulations relating to the drilling operations. These regulations are contained in Title 30 of the Code of Federal Regulations, Parts 250 and 25', and implement the provisions of the OCS Lands Act as amended. These regulations specify that a vessel conducting scientific research on the OCS must obtain a permit from the Area Supervisor, Conservation Division, USGS, if the exploration includes the use of solid or liquid explosives or involves the drilling of a deep stratigraphic test. Otherwise, a formal notice of intended operations must be filed with the Supervisor.

All drilling operations on the OCS must be conducted in accordance with applicable statutes, implementing regulations, OCS Orders, permit stipulations, and written and oral orders of the Supervisor. Deep stratigraphic tests would be subject to unannounced inspections by USGS inspectors who would check for compliance with Orders and regulations.

Various other permits must be obtained and regulations observed when drilling on the OCS. An Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) permit controlling waste discharge and a Corps of Engineers permit for structure placement in navigable waters are required. U.S. Coast Guard regulations as to the certification and inspection, safety, and design of equipment on the

vessel must be observed. Foreign flag vessels do not require U.S. Coast Guard certification if they have a foreign certificate of inspection recognized by the U.S. Coast Guard. Information concerning these various permits may be obtained from the following addresses:

U.S. Environmental Protection Agency
Division of Oil & Special Materials Control
Office of Water Program Operations
401 M Street, S.W.
Washington, D.C. 20460

Department of Army
Office of Chief of Engineers
Regulatory Functions Branch
(DAEN-CWO-N)
Washington, D.C. 20314

U.S. Coast Guard
Office of Merchant Marine Safety
Room 8300
Nassif Building
400 Seventh Street, S.W.
Washington, D.C. 20590

In State waters, normally defined as lying within 3 miles of shore, State drilling requirements must be followed rather than those of the USGS. The concerned States must be contacted to determine their individual requirements.

It is impossible for us to forecast future regulations that might affect your program. Each concerned agency should be questioned on this matter. The regulations which the USGS administers are currently undergoing change or have recently been revised. No changes that would significantly affect geological or geophysical exploration for scientific research are contemplated. However, OCS Orders Nos. 2 and 3 which govern drilling and abandonment procedures are always subject to revision because of improvements in drilling methods and techniques. Enclosed are copies of regulations currently in effect and a set of Gulf of Mexico OCS Orders. Prior to drilling in an OCS Area, the Area Supervisor can provide you with the latest regulations and applicable OCS Orders.

The USGS has little information on the requirements imposed by foreign governments for scientific drilling. Certainly, the country involved should be contacted. A good source of information on this subject would be a drilling company that operates worldwide such as ODECO or Zapata.

Addresses for these two companies are:

ODECO
1600 Canal Street
New Orleans, Louisiana 70161

Zapata Off-Shore Company
Zapata Tower
P.O. Box 4240
Houston, Texas 77001

Please contact us if we may be of further assistance.

Sincerely yours,

ACTG Chief, Conservation Division

Enclosures

APPENDIX D

Coring and Core Recovery

Introduction

Since the acquisition and analysis of core samples is such a vital element in the Ocean Margins Program and all deep sea drilling for science, attempts should be made to improve the quality and quantity of samples or cores as well as to improve the continuity or percent recovery. In some cases, this can be done by continuing development of present tools now under development; in other cases, further research and development of new tools, procedures, and instrumentation will be needed.

Proposed Core Diameters

The required bit and core size at total depth will determine the casing, riser, and drill pipe configuration. The hole program should be designed so that the minimum bit size is 6-1/8" at total depth. This size in a diamond bit could recover a 2-1/8" diameter core. Although it is possible to build a 6-1/8" diameter roller cone bit using cutters from a 4-3/4" standard bit, such a design would likely lead to short bit life, loss of cones in the hole, and very low penetration rates. The 6-1/8" diameter bit would be used to drill below the 7" casing point. Provisions should be made for running 5-1/2" casing if required in extreme circumstances. Drilling could then continue with a 4-3/4" diamond bit recovering 1-1/2" core to total depth. This would require 2-7/8" drill pipe. Extended drilling in this small final hole would likely be inefficient with increased risk of stuck pipe, twist-offs, and low penetration rates and bit life.

Core sizes in the shallower sections of the holes could be as follows:

0-50 meters	4-1/2" to 5-1/2" diameter core recovered by the giant piston corer in a separate deployment.
0-200 meters	2-1/2" hydraulic piston corer run through the 5" drill pipe until sediments begin to lithify.
200 meter (approx.) to the 9-5/8" casing point (about 3,000 meters)	minimum 2-1/2" core can be recovered utilizing roller cone insert or other bit designs.
Below the 9-5/8" casing to the 7" casing point	minimum 2" core can be recovered utilizing roller cone inserts or other (diamond) bit designs.
Below the 7" casing point	approx. 2-1/8" diameter core cut with a 6-1/8" diameter diamond or Stratapax bit.

Engineering Requirements

High-quality, undisturbed samples are very important in connection with engineering considerations, particularly in shallow formations that affect bearing capacity of the re-entry cone and the axial and lateral support of conductor or casing. Present tools such as the giant piston corer and hydraulic piston corer can provide the desired quality samples from the mudline to a depth where induration precludes or limits use of the hydraulic piston cores.

To be of engineering assistance to the program, high-quality sampling must be accompanied by strength tests that will permit rationale analyses of core/conductor problems. In addition to strength properties, consideration should also be given to accurate water content, unit weight determinations, and to plasticity. Tests to determine stress history would be interesting in the engineering as well as the scientific sense, but would not be essential in resolving initial engineering problems.

In indurated formations or in alternate hard and soft layers, additional attention needs to be given to maintaining uniform bit weight and monitoring this weight to improve core quality as well as recovery. In difficult formations, shorter core runs may also result in better quality and recovery and would permit better interpretation of the profile in terms of sequence and thickness of significant features or events.

Scientific Requirements

The core sample provides a record of the geologic and paleoclimatic history of the site. To obtain the most accurate scientific data, the core must be recovered and preserved in as close to in-situ conditions as possible. Specific requirements for a viable core sample include:

- Core orientation--desirable to determine directional rock properties (paleocurrent data, paleomagnetic data, and tectonic stress);
- Continuous coring--the preservation of a complete vertical section of rock/sediment is required for accurate, time-stratigraphic, and depositional environmental studies;
- Preservation of internal sediment/rock structures (lamination, mineralization, grain-size distribution), which are key to understanding the evolution of the sediments or rock types;
- Preservation of reservoir rock properties (in-situ permeability, porosity, and fluid saturations), which are necessary to evaluate the hydrocarbon resource potential at that particular site; and
- Preservation of in-situ stress distributions, which are key to interpreting the tectonic activity to which the rocks were subjected over the geologic time interval represented by the continuously cored interval.

Improvement of Core Quality

Several aspects of sampling operations should be improved or developed with the goal of improving the quality of recovered samples and improving the recovery rate of sampled intervals:

a) Upper 20-50 meters: Engineering needs for reliable geotechnical data as well as scientific requirements point to a need for high-quality, large-diameter, continuous samples of the softer sediments. The large-diameter (4-1/2"-5-1/2") piston corer system being developed as part of the long core facility (LCF) offers the best method of achieving these goals in an efficient, cost-efficient manner. The corer will permit "routine" coring of the upper 50 meters with a turnaround time of several hours. Lighter versions exist that can recover

cores to depths of 30 meters. The complete LCF system should be operational in 1982. LCF will be a complete and portable system including winch/cable, handling system, corer, instrumentation package and core processing facility. The LCF and the hydraulic piston corer, which is discussed below, are considered to be complementary systems to enable recovery of high quality samples of the upper 100 to 200 meters of the sediment column.

Coring Systems Status and Requirements

Hydraulic Piston Corer

Present designs take a nominal 15′ long x 2-1/2" diameter core. High quality core can be recovered in sediments to shear strengths of about 1 kg/cm^2. Development plans are to increase core lengths to 30′ by deep sea drilling program at Scripps.

Coring Bits

Currently, only larger (9-7/8"-9-5/8") roller cone bits are readily available. Bit companies have been reluctant to manufacture other sizes. The new possible bit sizes of 12-1/4" and 8-1/2" require new design. The conventional approach to the new designs is to find suitable cones from smaller bits to mount around the core area. Generally, larger cones have better bearing capacity; therefore the 12-1/4" bit can be designed using either 9-7/8" or 10-3/4" cones. The development should not be difficult; however, interest in commercial development of the bit is not clear at this time.

For the smaller bits such as 8-1/2", cones can come from either 6-1/2" or 6-7/8" bits. These cone sizes are not noted to have good bearing life and will probably require improvement. Insert cutter life has not been a significant problem to date. In the future, larger drilling runs may require cone designs that are unique to core cutting for proper cutting action. Use of drag elements of diamond, tungsten carbide, boron carbide, or polycrystalline diamond should alleviate wear problems on the core OD cutting. This appears to be a benefit on "core quality".

The required next steps for the NSF program office would be to contact organizations engaged in bit development and assess new products which may become available for the deep penetration program. Lacking current effort, some attempt should be made to establish sources of supply.

Orientation Systems

A prototype system has been developed for the hydraulic piston corer and field tests are underway.

Core orientation for hard rock has been attempted by DSDP but present designs have not proved sufficiently rugged and reliable. Improved systems should be dc .oped.

Extended Core Barrel (XCB)

The deep sea drilling program at Scripps is preparing machine drawings for the XCB prototype. The system is designed to increase core recovery and quality in interbedded hard and soft layers where the softer material is washed away by the circulation fluid. The design allows a nose to extend some 5 to 15 inches ahead of the bit in soft layers and retract when hard layers are encountered.

Core Indexing

A coring problem of particular concern in softer rocks when the hydraulic piston core is used in indexing of sequential cores: that is the initiating of a succeeding core run at the point of termination of a previous core run. Thus, if more and better cores are to be recovered, the problem of indexing successive core runs must be addressed and solved. One approach would be to attempt to assure by a positive drill pipe rachet--an advance "incrementer" device--that will allow a precise drill-ahead determination based upon the record of core recovery in the immediate past.

An alternate approach might be to take the soft, unconsolidated cores in an adjacent hole. This solution approach may also be confounded by drill pipe heave.

Positive Control of Bit Load and Torque

A major need in all continuous coring for high quality and reliability of core quality is the development of a downhole mechanism for positive control of bit load and torque during all crystalline-rock coring. This type of control is vital for successful use of diamond core bits or polycrystalline diamond bits. Use of an advanced heave compensator is also mandatory. At this time, it is very difficult to take diamond cores in deep crystalline rock.

Also, currently there is no known way to make a tri-cone and core bit that can be run through 7" OD† or 5-1/2" OD casing. Above 7-7/8" OD bit, it is possible to consider hybrid, four-cone-plus-polycrystalline (artificial) diamond core bits. Exploration of the possible extension down to a 6-3/4" diameter hybrid core bit may be done. However, all diamond bits (i.e., sizes of 4-3/4" and below) will require an research and development effort and a design and development project to perfect a downhole hold-down sub. Such a tool should assure that positive contract and bit load maintenance can be achieved. Without such a device, experience indicates that poor core recovery and very short bit life will result.

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†Outside diameter (OD).

Polycryst . Diamond-Core Bits

A recent development in drill bits has been achieved through the use of polycrystalline diamond "chips." These elements have engendered a new family of drag bits that may have valuable application to core bit design. Since the polycrystalline elements are larger than conventional diamonds, a greater latitude in bit design (e.g., hydraulics), enhanced cutting rates, core trim (OD) control, and opportunity for larger core diameter for a given hole diameter (as compared to a roller cone based design). A possible drawback is the relatively high torque requirements and the questions of hard-soft layer transition performance.

Recommended Approach to New Core Bit Design/Development

Early contacts and liaison should be initiated with the appropriate bit manufacturers. Early contact with these firms and dissemination of the advanced deep sea drilling program core requirements will assure timely development and delivery of the needed special bits on a schedule compatible with the scientific objectives of the program. In addition, these development efforts should be strongly supported by a comprehensive laboratory test and evaluation program. This should help ensure an optimum use of the time at sea.

Instrumentation

Efforts should be made to provide instruments to acquire information during or subsequent to drilling. Some of the measurements will be of interest primarily for scientific purposes whereas others are related more directly to the actual drilling process. The intention here is to provide a tentative "shopping list" of possible measurements that should be considered. In any event, an assessment must be made on the importance of these measurements to the program.

Science-Related Measurements

The following is a list of parameters that would be of definite scientific interest. Others no doubt could be added. The scientific community should be polled to get ideas and suggestions.

a) Temperature. Information on temperature profiles would be of value in calculating heat flow.

b) Porosity/Density: In-situ measurement of porosity and/or density would provide information on vertical variation of physical properties and help diagnose the sediment column.

c) Permeability: In-situ measurements of permeability characteristics would provide data necessary to calculate the rate of water migration.

d) Shear strength: A gross indication of strength properties could be arrived at by monitoring the penetration resistance (force) during advance of the hydraulic piston corer. A more direct method would be to develop an in-situ vane-shear device to measure the shear strength ahead of the coring barrel in the undisturbed sediment.

e) Acoustic velocity: In-situ measurement of acoustic velocity would provide valuable data on variation in physical properties.

Drilling Related Measurements

Should coring be required at small diameters (7-7/8"), it may be necessary to measure drilling parameters at or near the bit. An assessment of the usefulness of the following information needs to be made.

- Weight on bit.

  Long drillstrings and vessel motion can cause severe overload on either small roller cone bits or drag element bits. Measurements of and control of bit weight may be required.

- Acceleration.

  Bit dynamics have an effect on drilling and probably on core quality. A near bit instrument package should include axial and angular acceleration changes in measurements. Bit problems may be detected by acceleration patterns.

- Inclination.

  Hole deviation/inclinations are potentially of interest for drilling control and scientific data.

- Rate of Penetration.

  Rate of advance can help evaluate drilling or coring methods. Bit wear or bit failure are indicated by changes in the rate of penetration.

- Differential Rate of Penetration.

  The rate of core loading compared with bit advance is a useful measure of core quality.

The value of these measurements to coring or drilling activity have been long established. They may be even more significant for drilling from the *Explorer*.

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